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Integrated Scheduling and Information Support System for Transit Maintenance Departments

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Integrated Scheduling and Information Support System for Transit Maintenance Departments

by

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DEDICATION

To my family

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I would like to thank Dr. Grisselle Centeno for her guidance, support, dedication, and motivation throughout these years of study. Her commitment has been decisive to the success of this journey.

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INTEGRATED SCHEDULING AND INFORMATION SUPPORT SYSTEM FOR TRANSIT MAINTENANCE DEPARTMENTS

Paula Andrea Lopez-Alvarado

ABSTRACT

The projected increase of population in the United States and particularly in the state of Florida shows a clear need of improvement in mass transportation systems. To provide outstanding service to rides, well maintained fleet that ensures safety for riders and other people on the streets is imperative.

This research presents an information support system that assists maintenance managers to review and analyze data and evaluate alternatives in order to make better decisions that maximize efficiency in operations at transportation organizations. A system that consists of a mathematical scheduling model that interacts with a forecasting model and repair time standards has been designed to allocate resources in maintenance departments. The output from the mathematical models provides the data required for the database to work.

Although the literature presents several studies in the field of maintenance scheduling and time standards, it stops short in combining these approaches. In this research, mathematical methods are used to forecast repair jobs occurrence to react to increments in service demand. Furthermore, an integer programming scheduling model

that uses the data from both, the developed time standards and the forecasting model is presented. The information resulting from the models is entered to a database to create the information support system for transit organizations. The database gives the scenarios that facilitate optimizing the allocation of jobs in the facility and determines the best workforce for each required task.

Information was obtained from observations at three transit facilities in the Central Florida area; the model developed is tested in their scenario by using historical data of the maintenance jobs currently performed. Outputs obtained from testing have demonstrated reduction of operational costs, increased bus reliability, and efficiency in the tasks executed. Therefore, the present study aggregates value to transit organizations.

CHAPTER 1

INTRODUCTION

According to the United States Census Bureau, the population is estimated to increase in high proportions in the near future. California reports to be the most heavily populated State and the one that expects to grow in the highest proportion. Texas and Florida are expected to be the next biggest gainers. Florida is projected to add 2 million immigrants and after California and Texas should see a net gain of nearly 4 million from other States. www.census.gov/population/www/pop-profile/stproj.html Figure 1 presents the net population change for States gaining at least 1 million persons from 1993 to 2020.

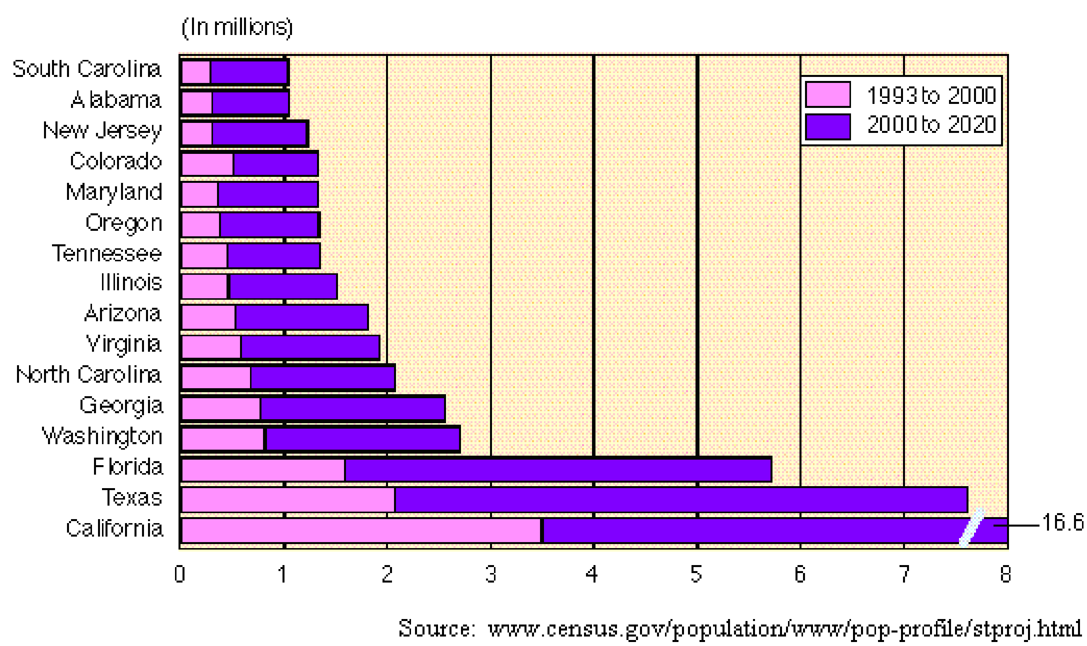

Figure 1: Net Population Change for States from 1993 to 2020

As it is seen in figure 1, there is a steady increase in population forecasted for the upcoming years that makes necessary improvement in the public transportation service. According to the Hillsborough County Metropolitan Planning Organization (MPO), by the year 2025, the population in Hillsborough County is expected to increase by 41% and the employment in the area is forecasted to increase by around 62%. Along with this, the total Vehicle Miles Traveled (VMT) is expected to increase by 52%. However, the planned roadway capacity is not expected to increase as much as the demand. These increments of demand force transit companies to develop better services since public transit in general represents an important factor of growing as a way to improve mobility http://www.hillsboroughmpo.org/about/index.htm.

Excellence in service starts from the base of public transportation organizations where maintenance departments play an important role. High demand of service results in a need for providing efficient and effective maintenance to the fleet. The statistics presented and their implications in efficient maintenance practices are motivators for the development of better systems that help managers improving productivity.

In this research, maintenance information from public transit facilities is explored using analytical tools to develop an integrated maintenance information system. The system developed is intended to assist managers in the optimization of maintenance operations, therefore efficient and effective service to the fleet.

Figure 2 illustrates how the study generates a coordinated system that processes the relevant information and supports the maintenance facility decisions while giving administrative alternatives to maintenance managers.

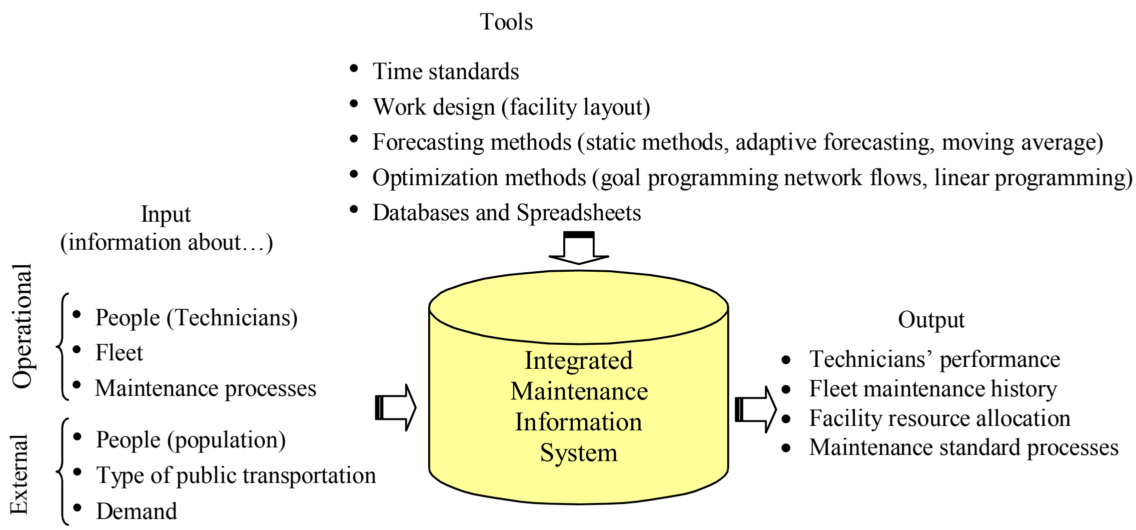

Figure 2: Model of the Integrated Maintenance Information System (IMIS)

The system inputs are grouped by factors associated with the transit environment that affects maintenance departments. All the factors should be connected to give better service to the customers and reduce potential damage to the environment.

- Operational factors: represent the basic information that the system requires to work including data about technicians, fleet, and maintenance processes.
- Environment or external factors: correspond to the factors that drive the demand of maintenance jobs.

Different tools can be used to develop the maintenance scheduling and information system. The specific methods used for this research and complete descriptions of them are presented in chapter 4:

- Work analysis: tools such as time studies and work design can be used to determine work efficiency in the facility. These tools play an important role in the standardization of repair fleet processes as well as in the measurement of workforce performance.

- Forecasting methods: depending upon the variability of the factors that influence the maintenance demand different methods of forecasting maintenance occurrences are used.
- Optimization: a linear programming model is used to determine the best allocation of resources in the shop.
- Software tools: databases and spreadsheets are used to develop the interface between the model and the end users of the information system.

Figure 3 presents how the proposed work scheduling model could impact the allocation of transit maintenance resources to increase efficiency and effectiveness in the facility. The inputs for this model are the forecasted demand of bus maintenance, the workforce availability, the physical capacity of the facility and the repair time standards developed. The work scheduling will assist managers in how to allocate their resources and to better plan training sessions that will positively impact the functioning of the facility.

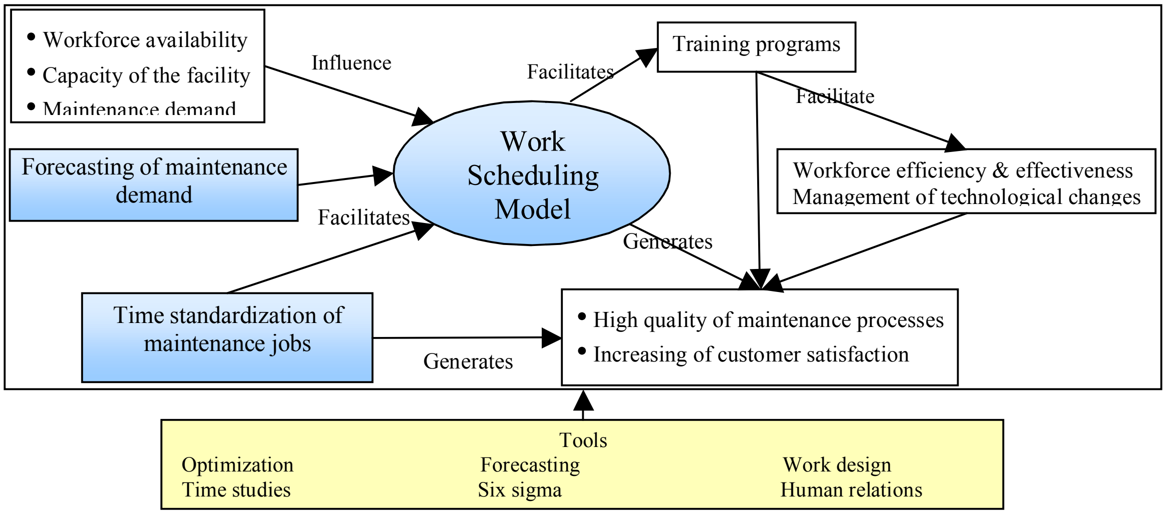

Figure 3: Work Scheduling Model Interaction

1.1 Scheduling Situation in Transit Maintenance Facilities

The scheduling system currently in place at transit facilities is shown in Figure 4. The flow shows that for the preventive maintenance (PM) case, the buses are sorted according to their daily mileage, information that serves as the base for maintenance scheduling. Additionally, if the buses need to be repaired they have to be assigned to an empty bay. The main constraint for maintenance scheduling is bay availability in the facility; a factor that prevents the prompt execution of more jobs due to the facilities' physical space limitations. After the buses are pulled out from the route, technicians are scheduled, based on the type of maintenance tasks to be performed on the particular bus. If there are no technicians available the bus is parked idle.

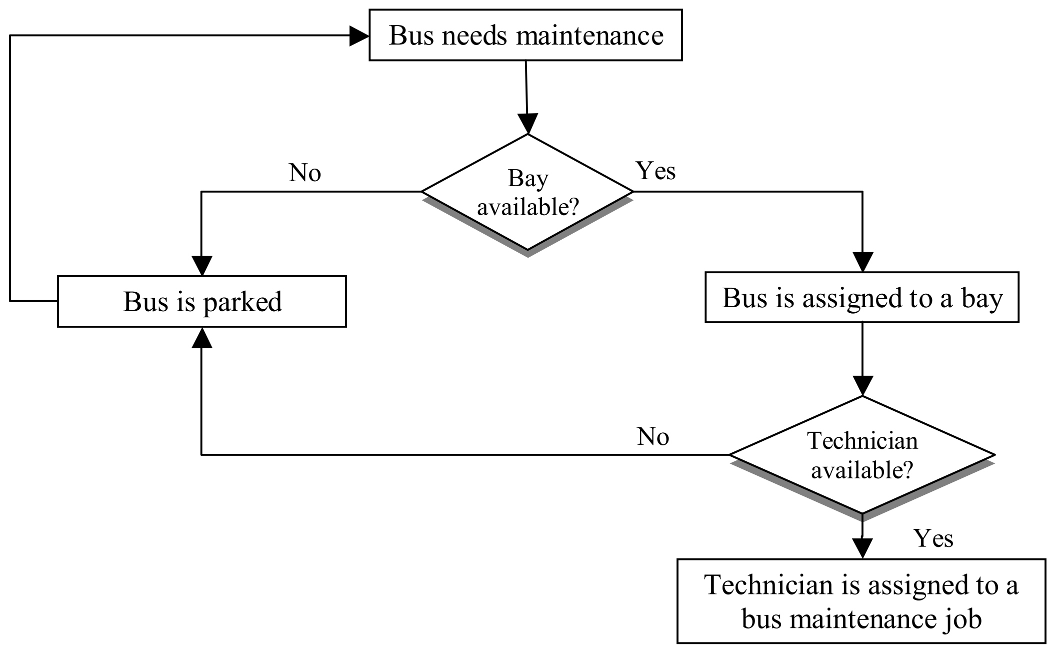

Figure 4: Current Scheduling System

1.2 Proposed Scheduling Situation in Transit Maintenance Facilities

The proposed scheduling model is similar to the current system but takes advantage of the repair time standards study to allocate more buses for maintenance in a shift, and to assign the best qualified technician to the job (see figure 5). Here, depending upon the work load and the time available, either one or two jobs are assigned to a bay during one single shift, which maximizes the resource utilization of the maintenance facilities.

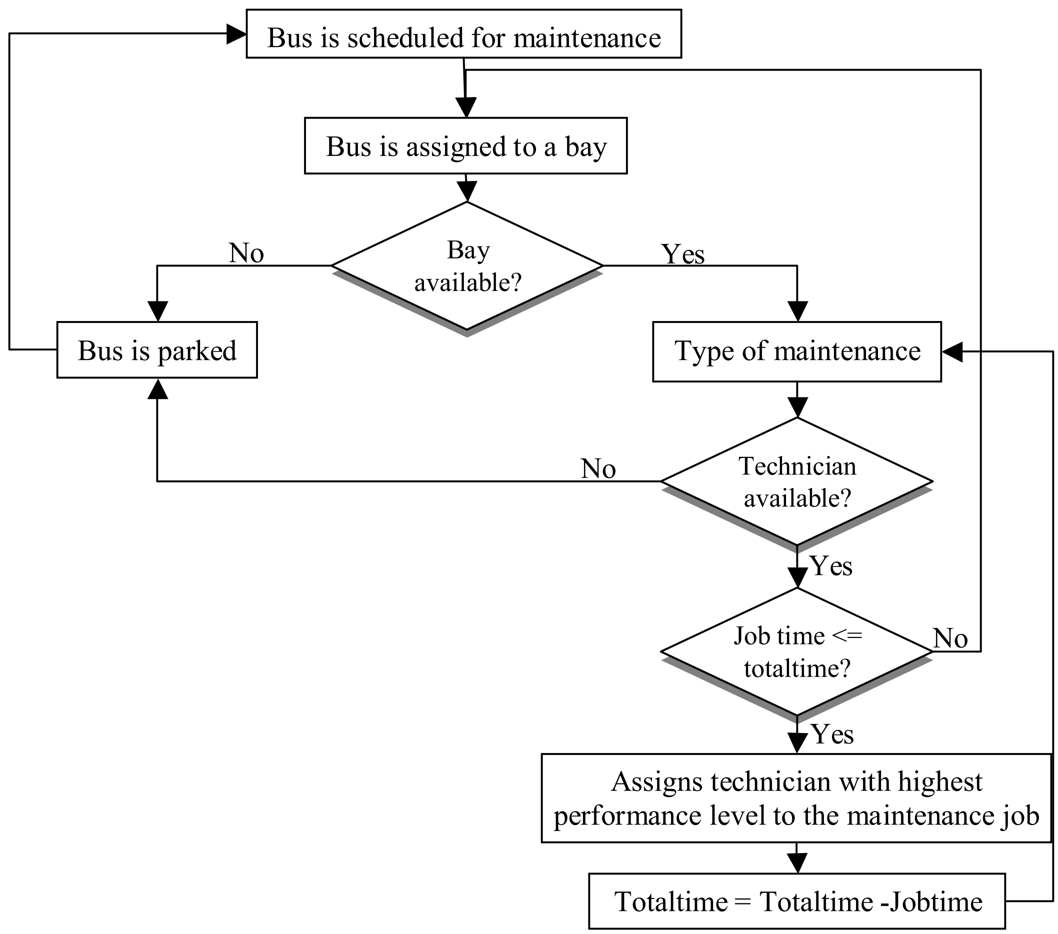

Figure 5: Proposed Scheduling System

Repair standard time is a factor that could constrain the number of jobs to be assigned to a particular bay as well as to a particular technician. If a job could be completed in half a shift or less, another bus could be assigned to the bay for additional repair or procedures. Likewise, if the job's standard time is higher than the time available in the bay, the bus is assigned to a new bay. A bus is parked only if there is no technician available to perform the required job. Since the model attempts to improve productivity, technicians could be assigned to more than one job during the day depending upon the type of job to be performed.

Efficiency is increased when the best allocation of maintenance jobs is made and fewer buses are parked to wait for service. Similarly, quality is improved by using standard repair processes and constantly following up with technicians' performance. Finally, training is better assessed for this process and it is facilitated by using the time and process standardization which promotes better execution of the jobs.

1.3 Thesis Organization

This thesis have been organized as follows: Chapter 2 identifies the most significant studies related to transit systems. Chapter 3 describes the problem statement and the motivation for the research. Chapters 4, 5 and 6 present the time standards, the forecasting model, and the scheduling model developments and evaluations. Chapter 7 includes the integrated maintenance information system and application. Finally, Chapter 8 presents the conclusions and recommendations of the study, including future research opportunities.

CHAPTER 2

LITERATURE REVIEW

A vital issue for safely operating transit systems is the appropriate maintenance of vehicles and equipment. According to the Federal Transit Administration (2001) safe vehicles prevent accidents and reduce risks to the driver, passengers, or other vehicles on the road. Maintenance practices must be regularly addressed to ensure that there is no unsafe vehicle on the road.

To improve management of transit maintenance departments, tools such as work standards, work scheduling, forecasting methods and management information systems could be utilized. The following sections summarize the work conducted in these areas, and discuss the impact in transit maintenance.

2.1 Time / Work Standards

Different studies have been developed to establish fleet maintenance time standards. Most studies have been built based on historical data and time estimations. Their main objective is to determine, and further control, the workforce performance in transit maintenance facilities.

Inaba (1984) reviews the use of work standards for transit bus maintenance. Different agencies from the U.S. and Canada were surveyed to determine if they used work standards and to what extent. According to this study, most programs had standards for inspection, PM, corrective maintenance and unit repair. The least attention was given to troubleshooting. The study also showed that work standards were used to identify problem areas, establish manual work schedules and to monitor personnel performance. The work standards programs of the Chicago Transit Authority and of Metro Transit of Seattle had the most extensive documentation. In this study, historical information and the generic steps to develop work-motion studies were used to standardize maintenance processes for transit fleet.

Purdy (1990) presents a methodology that uses historical data from an information system to establish preliminary work standards for division performed maintenance. The research objectives were centered on three aspects: to identify components that account for significant consumption of maintenance labor; to develop tools to increase workforce productivity; and to provide guidelines for daily and annual maintenance planning. Once again, it was found that most of the standards used in transit facilities are based on estimations from historical information.

Schiavone (1997) summarizes the work standard approaches employed by four transit agencies and a private company. He also presents the different methods used to monitor maintenance performance. The report reveals that many transit agencies expect maintenance employees to adhere to written procedures when performing routine tasks. Many agencies use original equipment manufacturers (OEM) service manuals as the base to establish their own work procedures and time standards. Other agencies have based standards on a combination of OEM and historical repairs rather than using on-site analytical methods.

Venezia (2004) summarizes information from transit facilities that have developed successful productivity improvement programs in order to gain insight into those properties' practices and procedures. The study presents data from transit companies that vary in terms of size, union, affiliation, and operating conditions. The results showed that many agencies use time standards as a guide to monitor employees and some others use them as a goal. Once again it was shown that most agencies use OEM, historical data and estimations to develop the standards.

As part of this study, a systematic method for determining repair time standards for transit buses is developed. The methodology analyses the flow observed on-site in three maintenance facilities to determine best maintenance practices. Furthermore, the current practices are analyzed and compared with the written procedures used at each participant facility. The analysis through various facilities and written procedures help in the generation of feasible and adaptable standards for transit facilities across the state and the nation.

2.2 Transportation Scheduling

Effective scheduling is necessary to optimize production lines and services. Martin-Vega (1981) demonstrated that the principle behind shortest processing time (SPT) sequencing could be applied to job shop bus maintenance. The use of SPT resulted in more jobs completed in less time and reduced waiting average time, which translates to a reduction in work-in-process inventory.

In public transit maintenance, the optimization of repair and inspection service represents minimization in costs and maximization of fleet utilization. Scheduling practices then serve as an efficient method to better utilize available resources.

Haghani and Shafahi (2001) developed a bus maintenance scheduling model to design daily inspections and maintenance schedules. The model maximizes the utilization of the maintenance resources while reducing the time that buses are idle when pulled from daily activities. This approach was focused on preventive maintenance (PM) scheduling, and presented both a mathematical formulation and a solution procedure.

The objective function has two components: The first is maximizing a weighted total vehicle maintenance hours (maintenance utility) for the buses that are pulled for maintenance when idle, and the second is minimizing the weighted total number of maintenance hours for the buses that are pulled out of their scheduled service for inspection.

Although the purpose of work maintenance scheduling is to ensure that the maintenance scheduling system runs efficiently over a period of time, other factors should be taken into account in order to implement an effective and efficient maintenance service system. Minimization of the operational costs, maximization of resources utilization, and need of high quality maintenance practices emerge as challenges for the public transit maintenance managers.

The research approach maximizes the number of buses served during a shift while optimizing the allocation of the resources according to the repair time standards established in the transit maintenance facilities. It does not only consider preventive maintenance (PM) jobs, but also repair jobs and road calls (RC). This model assumes that there is always availability of parts; otherwise, the jobs need to be re-scheduled when the parts are on hand.

2.3 Maintenance Forecasting

Transit facilities keep track of the occurrences of every job to generate statistics of the jobs performed each year. However, forecasting jobs based on previous occurrence is rarely done. Maintenance managers and supervisors are able to prognosticate and perhaps, schedule inspections due dates. Jobs such as PMs, engine and/or transmission repairs are planned based on mileage intervals, hours operated or fuel used.

No studies have been found related to transit maintenance jobs forecasting or using any scientific formulation to predict repair jobs occurrence. The study presented uses historical information as well as the traditional methods to develop mathematical forecasting approaches for maintenance jobs in transit facilities. It assists with the counting of coming inspections and also helps managers with the prognostication of possible break down occurrences.

2.4 Performance Measurements

When developing organizational or departmental improvements, it is important to conduct the post-implementation evaluation to assess the changes being done and to evaluate improvements. Applying quality measurements is very important after developing time standards for the various processes. They are necessary to keep track of the transit fleet maintenance and the technician's task accomplishment.

Guenthner and Sinha (1983) provided a method to link a maintenance model, a reliability model, and a performance evaluation model to evaluate the relation between the system operating performance and maintenance policy. The maintenance model provides the level of dependability as a function of the number of spare buses and the number of mechanics; the reliability model uses the dependability value to determine average passenger waiting times, based on the theory that undependable service will cause long waiting times, and the performance evaluation model quantifies the effect of waiting times on ridership and examines the overall system performance. The relationship between the three models presented in the study is shown in the Figure 6.

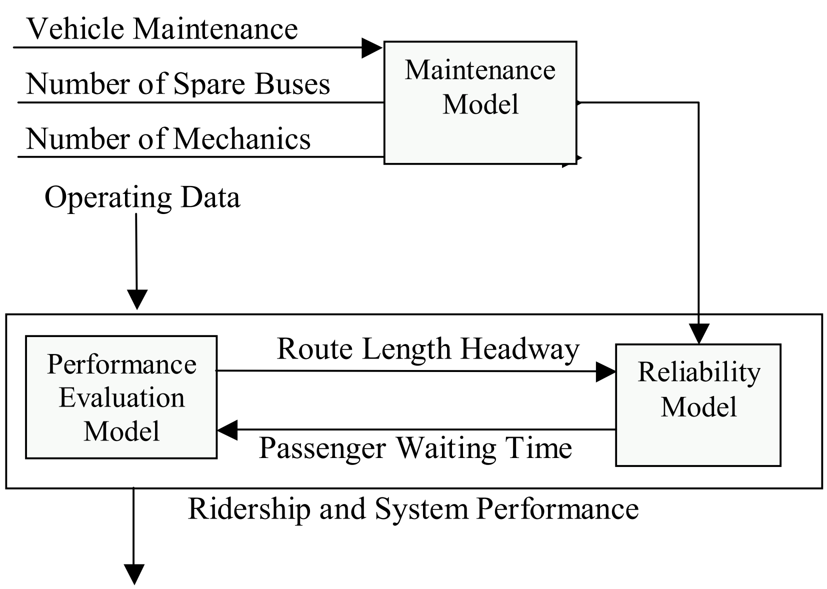

Figure 6: Relationship Between Maintenance, Reliability and System Performance Models

According to Inaba (1984), one of the applications of work standardization is to assure better maintenance scheduling based on individual judgments since it is easier to determine how long it should take for a particular technician to accomplish a job. For some of the agencies where standards were implemented, a system was also developed to compare the actual performance versus the standards.

List and Lowen (1987) report the results of a survey regarding bus maintenance performance indicators. They observe that RCs are the most important performance indicator followed by a turn inward to search for cause (i.e., drivetrain performance), and to monitor labor and monetary productivity. They also state that differences in managerial point of view appear to stand in the way of an agreement on a single list of indicators and their ranking.

As List and Lowen noticed, not all of the maintenance jobs and technicians' performance were always used to establish performance measurements. Computerized information systems emerged as a powerful tool to record any variability in technicians working and in the fleet operation. The integrated maintenance information system intends to relate data from maintenance departments in order to develop accurate and comprehensible performance indicators.

Schiavone (1997) summarizes the different methods that transit agencies use to monitor maintenance performance and illustrates how performance measurements are used to help shape maintenance programs. He identifies the key issues in elements of bus maintenance performance. Figure 7 shows the flowchart used by Schiavone to identify the key issues associated with maintenance performance monitoring (MPM) which include management philosophy, employee productivity, equipment performance and cost. The driven force of three factors on top is people. It is imperative for people to perform properly. Management philosophy refers to the role that managers play when motivating and training people to perform competitively. The employee productivity bases its rating on the way in which technicians perform their jobs. For this, time standards are cross-checked with their performance. Equipment performance will highly depend on how people perform. Better maintenance practices and good scheduling practices will result in better equipment performance and fewer RCs. Finally, these three approaches are closely related with cost since their accomplishment is translated into cost reductions.

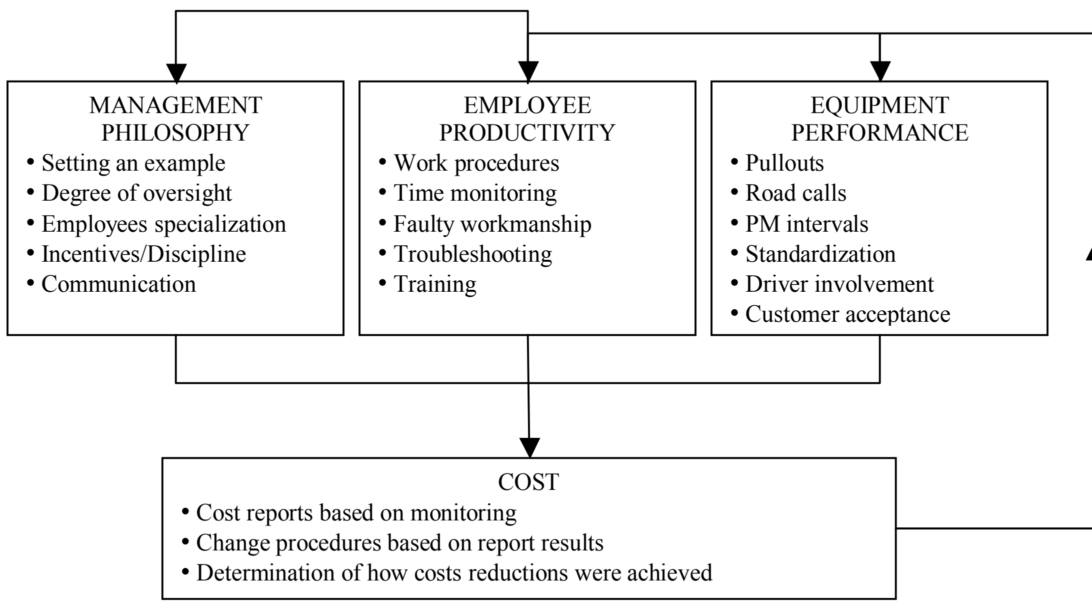

Figure 7: Flowchart to Identify Key Issues Associated with MPM

According to Shiavone's report, agencies usually develop their own maintenance performance monitoring program based on OEM service manuals, work orders and the Federal Transit Administration (FTA) National Transit Database (NTD). The study was conducted on four transit agencies and one private truck company.

Performance indicators are intended to reach for excellence. Therefore, transit maintenance departments should construct their own performance programs based on actual data and by applying quality standards. In this thesis, the time and process standards developed for three transit facilities is utilized to determine better flows that facilitate superior maintenance practices. Furthermore, it develops an IMIS to track and report technician's performance compared with the time standards established.

According to Venezia (2004), the most significant performance indicators are number of RCs, premature failures, pullouts, scheduled work compared with unscheduled work, repeated failures, and inspections completed on schedule. Although these practices are recognized by transit agencies, no systematic approach was found to accurately monitor these performance indicators.

The research presented in this thesis develops a scheduling model based on time standards. It can optimize resource allocation and assures reliable maintenance processes. These measurements would help to demonstrate the impact of processes standardization on RCs and the minimization of maintenance costs. After implementing the scheduling model based on the forecasted maintenance demand and using repair time standards as time constraints, the system needs to be evaluated. This approach intends to improve the transit maintenance system practice by preparing departments with tools that facilitate the fast response to unexpected situations that consume time from regular and scheduled tasks. This will reduce the number of unexpected break downs that affect the public transit service image and add operational costs to the companies.

2.5 Information Systems

Information Systems are widely used by management in areas such as allocation, distribution, scheduling, decision/risk analysis, and process management and control. Developers must use quantitative techniques such as mathematical programming, optimization models, statistical patterns, and forecasting techniques in order to exploit the IS and to facilitate the modeling of real environments.

In the public transportation field, diverse maintenance management models have been developed in order to keep track of relevant information. Managers use this information to manually schedule jobs and workforce. This system generates feasible solutions that typically are not optimal.

Etschmaier and Anagnostopoulos (1984) presented a typical transit system where three major functional elements support the entire system. However, maintenance departments are commonly isolated from the system and wrongly seen as the department that only increases costs to the company. Figure 8 shows how maintenance must be considered along with marketing and operations as major elements in a transit system.

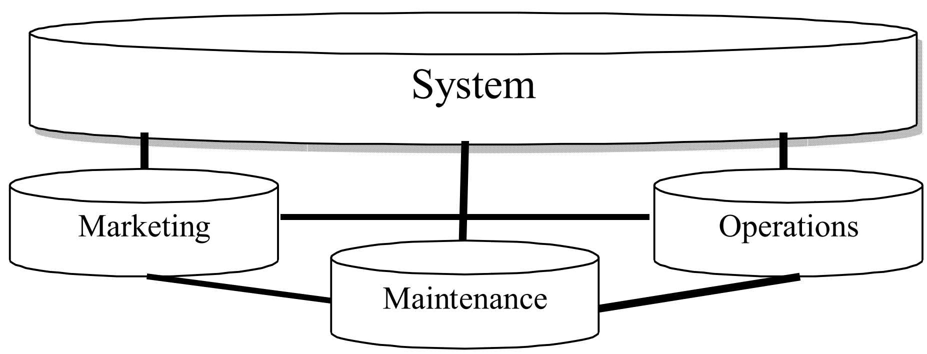

Figure 8: Typical Transit System (Etschmaier and Anagnostopoulos, 1984)

To change how people perceive transit maintenance departments, it is necessary to develop tools that help managers in attaining high productivity and moving the maintenance departments closer to the strategies of the company.

Boldt (2000) documents the state of the practice in management information systems (MIS) and compares communication technologies versus a contemporary background of business practice. The synthesis is organized into the basic architectural pieces that constitute an IT plan to provide the essential framework for the planning process. Additionally, he documents organizational issues and policies as well as market trends affecting the deployment of MIS technology.

The results have shown that the areas mainly evaluated by organizations are administration, planning and operations. As it is presented, although maintenance departments play an important role in organizations, they are not frequently considered as a relevant part of the company. However, transit organizations rely on maintenance departments to keep vehicles in safe conditions and to give outstanding service to the riders. Maintenance information systems should also be taken as an important part for companies to improve operations.

2.6 Other Transportation Applications

This section discusses maintenance scheduling application and optimization models developed for aircraft and railcar.

Hall (1998) developed a set of models to evaluate and compare the efficiency of alternative layouts for railcar maintenance. The model assesses two rules for assigning jobs to shop stalls, one is based on utilizing stalls in tandem with inserted idle time, and the other one without inserted idle time. In one of the cases modeled, jobs are selected for maintenance on the basis of repair and car characteristics. The cars are divided into maintenance classes represented by PM or repairs. It can be noted that when multiple tracks are available for shop lay-up, tracks can be assigned different classes, further reducing the expected number of moves. The models presented by Hall show the importance of facility design combined with scheduling as driven factors of efficiency in maintenance efficiency. Learning from the railcar scheduling and layout design experience, different approaches can be used to model the scheduling approach for bus maintenance, based on facility design. Shifts and bays can be arranged according to the demand needs to accomplish effective maintenance schedules.

Sriram and Haghani (2001) presented a formulation and a heuristic approach for aircraft maintenance scheduling and re-assignment. The model objective is to minimize the maintenance cost and other costs incurred for the re-assignment of aircraft to the flight segments. In this case, the aircraft is assigned to flights before maintenance is scheduled. These factors play an important role to determine which aircraft should fly which segment and when and where each aircraft should undergo the different levels of maintenance inspection. Only two types of PM are considered and unexpected requirements are not considered either.

As in the case of bus maintenance scheduling, the approach only considers PM tasks to allocate resources. Moreover, the model takes into consideration a short horizon of time to assign the aircraft to maintenance jobs.

2.7 Summary

In this chapter, the literature that is relevant to the presented research in the areas of time standards, forecasting, maintenance scheduling, and management information systems have been reviewed both from a methodological perspective and from a practical perspective. Since most of the related work is outdated, the presented review has concentrated on current practices and the fundaments required for solving the problem of interest. Table 1 complements the written discussion by summarizing the models encountered in the literature in the area of transportation maintenance systems. It is manifested that different studies can be potentially functional for maintenance departments but an integration of them is still needed.

The last item presented in the list corresponds to the proposed research and reflects how this study combines and updates approaches from the areas reviewed.

Table 1: Summary of Authors and Studies Related to IMIS Research

Author	Year	Title	Time/work Standards	Transportation Scheduling	Maintenance Forecasting	Performance Measurements	Information Systems	Transit Applications	Other Transportation Applications
Martin-Vega, L.A.	1981	SPT, Data Analysis, and a Bit of Common Sense in Bus Maintenance Operations: A Case Study		✓				✓	
Guethner, R; Sinha, K	1983	Maintenance, Schedule Reliability and Transit System Performance				✓		✓	
Inaba, K	1984	Allocation of Time for Transit Bus Maintenance Functions	✓			✓		✓	
Etschmaier, M; Anagnostopoulos, G	1984	Systems Approach to Transit Bus Maintenance					✓	✓	
List, G; Lowen, M	1987	Bus Maintenance Performance Indicators: Historical Development and Current Practice				✓		✓	
Purdy, J	1990	Work Standards: Their Use and Development Using a MIS	✓				✓	✓	
Schiavone, J.	1997	TCRP Synthesis of Transit Practice 22: Monitoring Bus Maintenance Performance.	✓			✓		✓	
Hall, R.W.	1998	Scheduling and Facility Design for Transit Railcar Maintenance							✓
Boldt. R.	2000	TCRP Synthesis of Transit Practice 35: Information Technology Update for Transit					✓	✓	
Haghani, A; Shafahi, Y	2001	Bus Maintenance Systems and Maintenance Scheduling: Model Formulations and solutions		✓				✓	
Sriram, Ch., Haghani, A.	2001	An Optimization Model for Aircraft Maintenance Scheduling and Re-assignment							✓
Venezia, F.	2004	TCRP Synthesis of Transit Practice 54: Maintenance Productivity Practices	✓			✓		✓	
Lopez, P., Centeno, G.	2004	Integrated Maintenance Information System for Transit Organizations	✓	✓	✓	✓	✓	✓	✓

CHAPTER 3

PROBLEM STATEMENT

Although the literature presents several studies in the field of maintenance scheduling and time standards, it stops short in combining these approaches. Time standards have been developed to increase efficiency in maintenance processes. On the other hand, scheduling models have been developed also to improve efficiency based on service waiting times. However, to the best of our knowledge no study that improves efficiency in transit maintenance operations by scheduling jobs based on time standards and estimations of demand was found.

This research integrates forecasting methods that model the behavior of the repair demand in transit maintenance departments. The results are used as input to a mathematical model that schedules resources such as technicians and bays in maintenance shops. The assignment is based on the importance of the repair type. Furthermore, the system uses repair time standards results to allocate as many jobs as possible to a shift. The use of repair standard times is fundamental when allocating the most experienced technicians. A database that integrates information from those systems is developed. It contains feasible, comprehensible, and useful reports to maintenance managers and supervisors. Figure 9 shows how the output from the models will interact with the database.

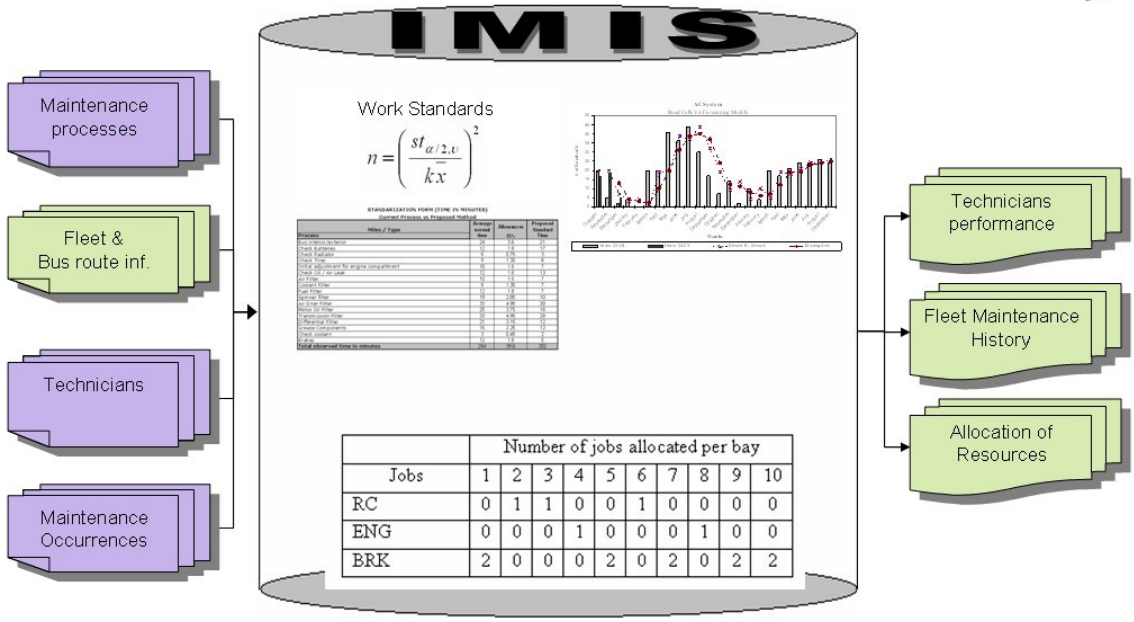

Figure 9: Integrated Maintenance Information System (IMIS)

3.1 Motivation

As it was explained in Chapter 2, several studies have been conducted in the field of maintenance in public transportation including scheduling, planning, process optimization and policies. However, most studies have been done over 20 years ago and they mostly show solutions that stand by themselves without considering the other planning components for maintenance management.

According to the Transit 2020 developed by the Florida Department of Transportation (FDOT) in collaboration with state and local government agencies, transit providers, community leaders and the general public: *"Transportation's needs into the 21st Century cannot be met with highways alone. Improved public transportation is crucial to expanding travel choices."*

(http://www.dot.state.fl.us/transit/Pages/transit2020plan.htm) This quotation emphasizes the need for improvement in public transit organizations in order to conserve a reliable fleet, and to meet the increases in demand.

The future of urban transportation represents a challenge to maintenance managers due to the foreseen high utilization of the fleet. Currently, the low demand of urban transportation denotes relatively low problems for scheduling and technicians' productivity. However, when demand increases the service should remain the same in quality and accomplishment. Since maintenance shops cannot increase capacity every time demand increases, a need for optimization is evident to compensate for high amounts of work.

Having reliable maintenance information systems that efficiently keep the information under control and supports managers when making decisions is a challenging task. It is necessary to count on reliable systems that can manipulate and organize the information related to the internal and external factors that may affect the functioning of the transit facility and result in a consistent accomplishment of maintenance tasks.

3.2 Managerial Motivation

A successful organization is the result of the combination of efforts from the various departments. Aligned administrative strategies could enhance the management of the transit fleet maintenance, and as a result, improve service to the riders. Maintenance departments play a fundamental role inside public transit companies. However, an assessment of transit operations has revealed that they are usually segregated from the rest of the company (Etschmaier, 1985). Typically, the main objective of these departments is to maintain the fleet working safely and reliably without breakdowns. For that reason, they should not be seen as a support element of the organization but as another core unit that aggregates value to the transit facility.

Maintenance managers receive information from many different sources in the organization which make their job tedious and difficult. IMIS is an information system that provides desirable and friendly support through interfaces with appropriate format. Moreover, managers will be able to test how different scheduling strategies would work under various conditions to consider alternative plans.

3.3 Research Objectives

The objective of this research is to develop a scheduling model that allocates resources at transit maintenance facilities, applying repair time standards developed and technicians' performance rating resulted from the standards. The scheduling satisfies an input demand that comes either from current needs or from the forecasting of previous demands. The development of a forecasting model that provides scenarios of demand represents another objective of this thesis. Also, this research aims to integrate the models in a database that works as a maintenance information system in order to assist maintenance managers and supervisors in the optimization of resources.

This study applies the model developed to the environments of three transit facilities in the state of Florida. A practical application of the models is presented to demonstrate the relevance of the models and how the environment of a transit facility might be impacted with the application of the proposed system.

CHAPTER 4

TIME / WORK STANDARDS DEVELOPMENT

Standardization of time and processes of maintenance tasks minimizes the time to perform a job while improving process development. Standards are useful to determine labor efficiency, to improve maintenance process control, and to improve facility layout. In this study, nine steps have been proposed to establish repair time standards. These steps cover the methodology shown in figure 10. The squares represent the steps followed during the development of the methodology and the rounded boxes represent the relevance of feedback of the people from the participating facilities.

The following section describes in detail the steps followed in the development of the standards at four transit agencies. The methodology and application shown in this section are extracted from Centeno, Chaudhary, Lopez, 2005.

4. 1 Task Identification

The first step is to identify the critical task or system to be studied; brakes, PM, or engine and/or transmission replacement are examples of the maintenance systems. The task(s) could be identified based on the priority for repair given at a transit facility. Factors that could be considered to choose the task include frequency of service, or tasks with failure components resulting in high risks or great loses.

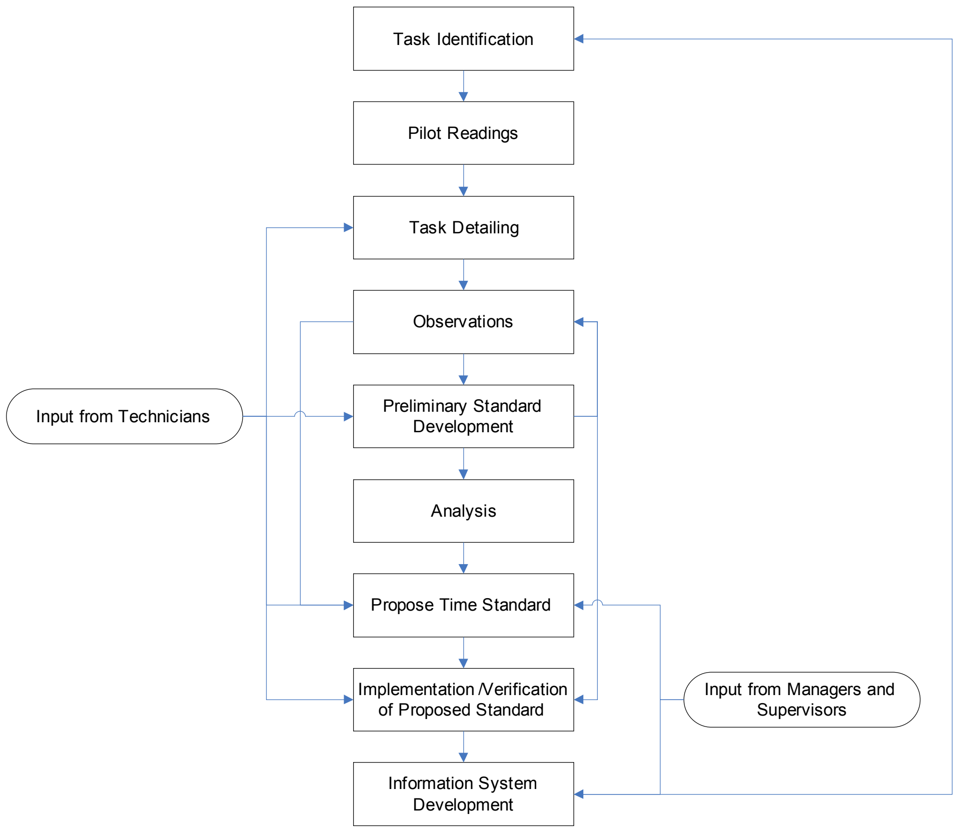

Figure 10: Repair Time Standard (RTS) Development Cycle

With the agreement of a steering committee and other officials from Florida Department of Transportation (FDOT), this study was initiated by identifying brake repairs as the first task to be studied. Brake repair is one of the most important systems in transit buses since failures on any of its components represent high safety risks and liabilities. The second job studied was PM since periodical inspections enhances the service life of the buses and increases safety. Additionally, PM is the task most frequently performed at transit facilities.

4.2 Pilot Readings

This step allows the analysts to become familiar with the process being studied. The development of the pilot readings required considerable experience on work measurement analysis as well as good knowledge of the transit industry and bus components. Initially, to understand the process of the jobs studied, various visits to the participating facilities were necessary to record the total time required to perform a task. The total time and procedure to complete the task was recorded for all the observations.

A typical concern from supervisors and technicians is the number of cycles that will be observed before establishing the standards. If only a few observations are taken, the standards could be questionable and/or erroneous. On the other hand, a big number of observations is very costly and time consuming. For that reason, the formula presented next is important to statistically determine the number of observations to be taken to have results in a 95% confidence level (Niebel, and Freivalds, 2003).

$$n = \left(\frac{s t_{\alpha/2,\upsilon}}{k \bar{x}} \right)^2$$

Where:

- *s* is the standard deviation (time in minutes) from the pilot readings taken;
- *t* is the statistic computed using an α (error) – typically set as 5 or 10% with *n-1* degrees of freedom (υ);
- *k* is the accuracy which measures the closeness of the observed value to the true value of the population – typically set as ± 5%;
- is the average value in minutes from the pilot readings taken.

The total number of cycles required for brakes job was computed to be 10.6 observations. To ensure the required accuracy, it was rounded up to 11 (Centeno, 2002).

$$n = \left(\frac{s t_{\alpha/2,\upsilon}}{k \bar{x}} \right)^2 = \left(\frac{1131.44 * 4.303}{0.1 * 14950.3} \right)^2 = 10.6048 \cong 11$$

Similarly, various visits were made to the participating facilities to observe the processes for the PM jobs. At the same time, related existent procedures and checklists were collected to gain a better understanding of the processes. Later, this information is used to facilitate the development of the proposed flow in PM activities. The total number of observations required for PM was 13.55. This number was rounded up to 14 observations.

$$n = \left(\frac{s t_{\alpha/2,\upsilon}}{k \bar{x}} \right)^2 = \left(\frac{624.5 * 4.303}{0.05 * 14600} \right)^2 = 13.55 \sim 14 \text{ observations.}$$

4.3 Task Detailing

With the completion of the pilot readings, the major processes within a task along with the elements should be identified. Processes are the major components in a task; an element is the smallest unit contained in a process. Oil change is an example of a process within the PM task, and removing the filter is one of the elements in the oil change process.

Each element should be studied and further classified according to the ASME standard set of process chart symbols as an operation, transportation, storage, inspection or delay (Niebel, and Freivalds, 2003). The definition and symbol of each classification is as follows:

○ *Operation*: Activity that involves performing work on a part

⇨ *Transport*: Movement from one place to another to perform an operation, part procurement or storage

□ *Inspection*: Observation of components to check conformity to the safety requirements

D *Delay*: Interruptions during the working process due to unnecessary (avoidable) or necessary (unavoidable) events. An avoidable delay is a pause in the productive work due to the technician non-work related causes, e.g., the technician is often out of his workplace for smoking. An unavoidable delay is an interruption of a normal process that is outside of the technician's control, e.g., the technician has to wait for the oil to drain.

▽ *Storage*: Event of accommodating parts on a different location

Classification of elements will provide valuable information of the workflow and facilitate the identification of redundant elements. Figure 11 shows the standard form developed to record the time taken to perform each element and provides a space to classify it according to the type of activity.

Time Study Worksheet (Facility and Job)
Flow Process Chart

Date:	________
Maintenance type:	________
Starting Time:	________
Ending Time:	________
Vehicle Number:	________
Characteristics:	________

Summary		Total Time
○ Operations		
⇨ Transport		
□ Inspections		
D Delays		
▽ Storages		

Work Elements	Observed Time (Sec)	Performance			Operation	Transport	Inspection	Delay	Storage	Normal Time (Sec)
		90	100	110						
Process 1										66.7
Element 1	20		✓		●	⇨	□	D	▽	20
Element 2	25		✓		○	➡	□	D	▽	25
Element 3	18	✓			●	⇨	□	D	▽	16.2
Element 4	5			✓	○	⇨	■	D	▽	5.5
Process 2										99.7
Element 1	14		✓		○	⇨	□	D	▽	14
Element 2	23		✓		○	⇨	■	D	▽	23
Element 3	12			✓	●	⇨	□	D	▽	13.2
Element 4	45			✓	●	⇨	□	D	▽	49.5

Figure 11: Time Study Worksheet

During the course of taking the pilot readings, all the processes and elements for each task were identified and studied carefully. The time of each element was as small as 3 to 4 seconds. For brakes, 10 processes and 260 elements were identified. For PM, 17 processes were identified. Similarly, nearly 300 elements were identified and classified.

4.4 Observations

When recording the observation the following criteria should be considered:

- The observations should be taken objectively to minimize bias while describing the elements and recording the times.
- The technicians chosen should perform at a normal working pace. Some of the observations may be repeated with the same technicians to check for consistency.
- If possible, observations should be taken during different shifts during the day to evaluate the impact of external factors such as surrounding light and weather.
- Observations should be taken with no special arrangements and the emphasis should be to develop standards for a typical environment. Moreover, special tools or equipment infrequently available should not be employed when conducting the study.

During the observations, the working pace of the technicians should be examined by the analyst and categorized as normal, below normal (slow) or above normal (fast speed). This practice is typically based on the experience and judgment of the analyst. Therefore, the analyst should be adequately train to assign fair and impartial performance ratings throughout the study. The time study worksheet previously illustrated (see Figure 11) contains three columns to evaluate performance on each element. When the operator performs at normal pace a 100% rate is assigned; below normal is accounted as 90% and above normal as 110%. Note that a given operator may perform at different paces during the completion of the tasks, thus, different percentages for the various elements could be assigned. For the elements rated as above or below normal the normal time could be obtained by multiplying the observed time to the rate.

4.5 Preliminary Standards Development

After completing taking the required observations, the workflow should be analyzed and the best practices among facilities should be combined to develop a standardized flow. The processes should be sequenced in such a way that redundant elements and elements that cause delays are removed. The preliminary standards are determined by combining all the valid observations and by taking the averages of the normal times for each element.

The following factors should be considered when developing the preliminary standards:

- Normal pace: Observed technicians should be encouraged and are expected to work at a normal pace.
- Worker habits: Habits that cause delays such as speaking to colleagues or conferring with others while borrowing tools should be evaluated and restricted without altering the actual processes. This will allow the construction of standards that are feasible, realistic, and easily adopted by technicians.
- Facility layout: To make the standards more robust and reusable, they should be developed independently from the facility layout.

- Actual readings: The preliminary standards should be based only on collected data from the pilot readings and not on theoretical studies.

Developing preliminary standards for PM was relatively more challenging than for brakes as it had many more independent components including inspection and diagnosis. Brake repair is more systematic which makes sequencing one process over other relatively more feasible than in PM. A modular approach that provides the technician with flexibility to perform the process in any order preferred without altering the total estimated time was adopted. Figure 12 shows the flow with the processes developed for a 12,000 type of PM.

4.6 Analysis

All the observations recorded should be compiled and compared to develop the best procedures for the facilities. The recorded times are analyzed to understand variability and to identify foreign elements. Foreign elements are unexpected occurrences during the job process that are not part of the regular course. Recorded times that include them should be removed and not be considered as part of the standards. An average will be taken from the remaining observations to obtain the normal time that will be used later on for the final proposed standard. A thorough evaluation of the observations must be conducted and elements that cause delays should either be removed or adjusted to reduce time and stress caused to the technicians. In addition, transportation/travel time can be minimized by appropriately re-designing the flow.

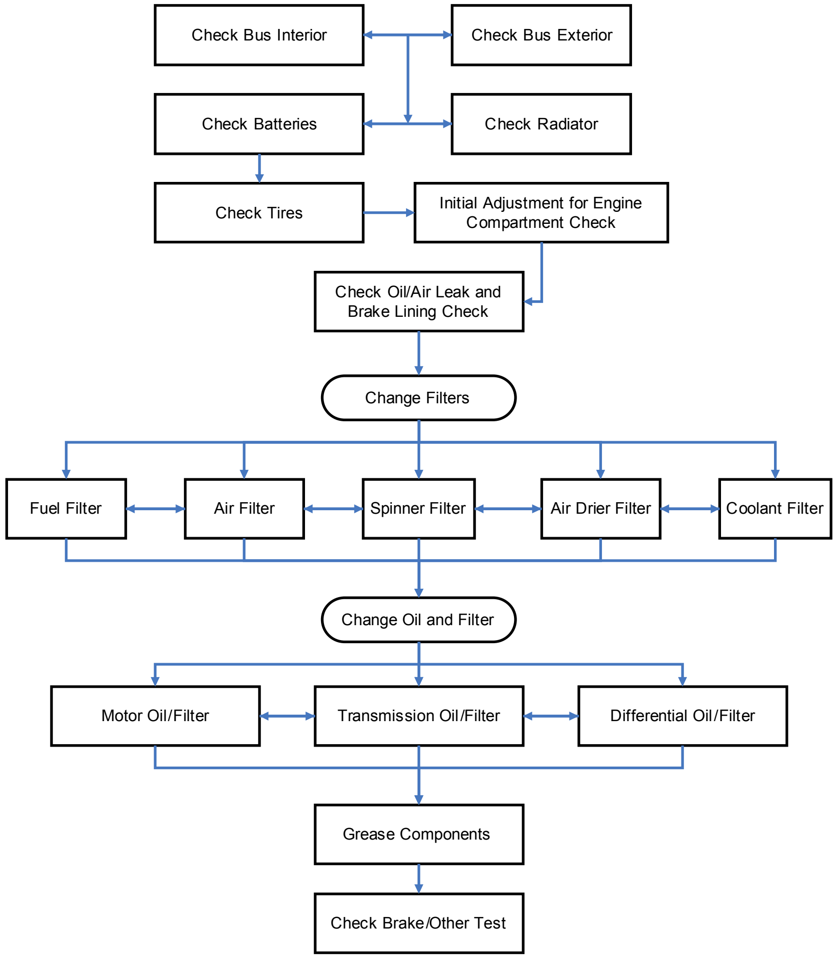

Figure 12: Processes for Preventive Maintenance

During the study, the observations taken were compiled and compared by evaluating the times for each element in all the observations. The elements were further classified and combined to improve workflow. It is recommended that before starting the job the necessary parts and tools set up must occur. That helps to reduce the number of trips to the warehouse or other bays while performing the repairs. Additionally, the technicians can be more focused on their job and thus increase the efficiency with lesser travel time. Foreign elements were separated from the regular elements. Many of them occurred due to non-availability of tools or due the lack of new replacement parts. Times indicating very high variation for a particular element were discarded. Finally, the average normal time was calculated from the remaining observations.

4.7 Proposed Time Standard

After designing a logical workflow, the proposed time standards can be determined. Factors such as personal interruptions and delays caused by going for a drink or to the restroom must be considered before establishing the standard. Fatigue due to repetitive activities or environmental conditions are other factors that can affect even the strongest individual and cause delays. Interruptions from supervisors or tool breakages may also impact the real time required to do the job. For these reasons, allowances must be added to the normal time in order to develop a fair standard. The allowances will enable the average technician to meet the established standards when performing at normal rate and ensure smooth and efficient working (Niebel, and Freivalds, 2003). The allowances that can be considered for the transit bus repair are:

- Personal Allowance: This includes those cessations in work necessary for maintaining the general well being of the employee.
- Basic Fatigue Allowance: This allowance accounts for the energy required to carry out the work and to reduce monotony.
- Standing Allowance: This allowance generally accounts for the energy consumed while standing.
- Intermittent Loud Sound Allowance: This allowance generally accounts for the sound made by the equipment and tools used.

- Tediousness Allowance: This allowance is generally applied to elements that involve repeated use of certain parts of the body.

Based on the percentage of allowances recommended by the Internal Labor Office (ILO), the total allowance assigned for this study is 15%. The percentages are divided as follows.

- Personal (5%): This allowance is for the general interruptions including drinking water, restroom, etc.
- Basic Fatigue (4%): This is given to the technicians, as they have to lift some heavy weight tools and equipment including the air guns.
- Standing (2%): Both, brake repair and PM are performed by the technician while standing.
- Intermittent Loud Sound (2%): This allowance is for the noise produced when using air guns and other tools that cause inconvenience to the technicians.
- Tediousness (2%): Some of the elements during repair are very tedious including cleaning S-cam or greasing assemblies. This allowance is meant to give some rest for such tedious operations.

Note: The time for lunch or related breaks can be included depending upon the shift.

4.8 Implementation/Verification of Proposed Time Standards

After the standards are developed, they should be verified by taking several observations from technicians working at normal pace. Beforehand, the technician should be provided with the information regarding the proposed standards and become familiar with the new workflow in order to smoothly follow the proposed sequence of elements. The set of recorded times should be compared with the standards proposed for consistency. In case of large differences, the observation and analysis phase should be repeated.

After proposing the standards, a technician, who consistently worked at a normal pace, was selected for verification of the brake standards. The recommended initial setup was practiced and the technician was provided with the proposed time standards and with the description of the new workflow. Repeatedly, the technician was able to complete the task in the specified time of the proposed standard (Centeno, 2002). Table 2 shows the summary of results from the repair standard time developed for brakes (Centeno, 2002) and PM jobs.

The time in the current method column reflects the time for one random observation taken at a facility. The percentage reduction gives an estimate of the average benefits from the standard developed. Most proposed standards take significant less time than the current method observed. The average percentage of reduction is over 51%. As seen in Table 2, all delays has been eliminated from the brakes job and reduced on 92% of the cases for PM. There is however an increase in the time for inspections in PM. This can be attributed to the fact that the technician working for that particular study may be very experienced to handle the inspection sooner than the average or may have not spent adequate time for the inspection.

Table 2: Results for Brake Repair and Preventive Maintenance

Element Classification	Brake Repair			Preventive Maintenance		
	Current Method	Proposed Method	Reduction	Current Method	Proposed Method	Reduction
Operations	156 min	131 min	16.67%	291 min	154 min	47.03%
Transports	60 min	26 min	60%	43 min	22 min	48.86%
Inspections	7 min	1 min	85.77%	15 min	22 min	-40%
Delays	22 min	0 min	100%	50 min	4 min	92%
Storage	0 min	0 min	-	0 min	0 min	-
Allowances (15%)	-	21	-	-	30	-
Fill Check List Details	-	-	-	-	20	-
Total Time	245	182		399	252	
Total Time in Hours	4 hours 5 min.	3 hours 02 min.	27.32	6 hours 39 min.	4 hours 11 min.	37.1%

CHAPTER 5

DEMAND FORECASTING MODEL DEVELOPMENT

Transit facilities usually plan maintenance routines based on mileage or time intervals depending on the process to be performed. Bus service manuals serve as guides for the transit facilities to determine maintenance intervals and forecast inspection requirements. The mileage interval recommended by the manufacturers assumes normal driving and fair environmental conditions. However, the frequency to perform jobs may vary according to the experience and judgment of the manager.

Major repairs can also be planned in advance by taking the manufacturer recommendations as well as the maintenance historical information. For instance, air conditioning (A/C) service is checked every time a PM is performed, but a deep maintenance is recommended to take place every year before the summer season, regardless of the mileage. Nevertheless, historical information shows that due to the inefficient methods to plan and predict repairs there is a high incidence of road calls (RC). For example, a high number of RCs on A/C jobs is typically seen during summer season.

RCs are defined as the occurrences of an incident while the bus is providing service. Accidents or break downs are examples for RCs. These types of calls are difficult to predict and when they occur, the maintenance facility must be prepared to take action immediately, and in an effective manner.

The objective of developing an effective forecasting approach is to accurately represent the most probable occurrences of regular and unexpected repairs and to give managers scenarios of possible incidences for opportune reactions. The forecasting model presented does not specify which particular bus will fail but predicts occurrences of breakdowns and anticipate fleet maintenance using historical information.

According to Martinich, 1997, the general characteristics of the different forecasting models include data behavior (when to use) and the forecasting time period required (see Table 3). Since maintenance departments keep track of the repair orders, the information collected can be used as the base for determining future service demand.

Table 3: Characteristics of Forecasting Models

Method	When to Use	Normal Time Horizon	Computational Complexity	Cost
Qualitative:				
Individual prediction	Little data Unstable environment	Intermediate	Low	Low
Group methods	Little data	Long term	Low	Moderate/high
Quantitative:				
Cumulative average	Constant process	Short	Low	Low
Simple/weighted moving av.	Quasi-constant proc.	Short	Low	Low
Simple exponential smooth.	Quasi-constant proc.	Short	Low	Low
Linear (trend) regression	Linear trend process	Intermediate	Moderate	Moderate
Double exponential smooth.	Linear trend process	Intermediate	Low	Moderate
Seasonality models	Seasonal process	Short / intermid.	Moderate	High

Given that the time horizon of the forecasting in transit environments is typically for the same day or week (short) and the data is quasi-constant (the data points look relatively constant), two methods for forecasting are considered: Moving average (MA) and simple exponential smoothing (SES).

Figure 13 shows another process considered to choose the method to be followed to select the best technique to forecast maintenance incidences. In this case, by evaluating the possible methods and analyzing the hypothetical results, the method that better represents the situation is chosen.

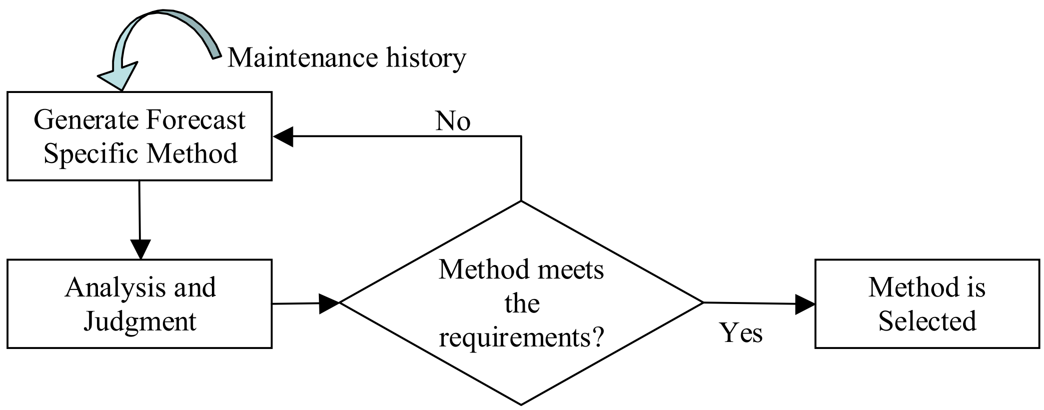

Figure 13: Forecasting Methods Evaluation

Based on table 3 and using the model evaluation from figure 13, both MA and SES are evaluated to determine the most accurate approach for predicting break down incidences.

The MA is based on a weighted average of past values. It represents a good option since it can be used to accurately model demand for short periods of time. The SES method is also considered since it is efficient to use when seasonal patterns are observed. When comparing MA vs. SES, it is noted that MA weights equally the past observations, while SES assigns relatively more weight in forecasting to recent observations.

The SES forecasting method is often used to model short term forecast of maintenance demand. It uses an iterative equation to revise the forecast for each period based on the accuracy of its most recent prediction (Martinich, 1997). In this way, maintenance supervisors can forecast for the immediate future repair demand to accurately estimate the scheduling needs ahead of time. This approach allows the maintenance department to optimize the allocation of technicians for the jobs based on their skills.

The following is the SES model formula:

$$F_{d+1} = F_d + \alpha\,(y_d - F_d)$$

- F_{d+1} represents the forecasted number of maintenance jobs
- F_d represents the number of maintenance jobs predicted for the day *d*
- α is the smoothing constant
- y_d is the actual number of jobs performed and used as a data point.

The values of α can vary from 0 to 1 depending upon the rate of reaction required for the maintenance department. A higher rate of reaction is represented by a value of α close to 1. The α value is used to smooth out the inaccuracy, so that the maintenance demand anticipations do not overreact when unexpected changes occur.

The MA approach represents the average of the N most recent data points (failure incidences). The smaller value given to N represents a more responsive demand forecast. The following is the MA formula:

$$F_d = (y_{d-n} + y_{d-n+1} + \ldots + y_{d-1}) / N$$

- F_d represents the number of maintenance jobs predicted for the day *d*
- N is the number of periods averaged
- y_d is the actual number of jobs performed and it used as a data point.

Table 4 shows the comparison of methods MA (N=2) and SES (α = 0.9) for a two years demand of brakes system incidences. It also shows the accuracy of the methods by computing the mean square error (MSE).

Table 4: Forecasting Methods Applied to RCs of Brakes Repair System

Month	Brakes System		Forecast	
	Years 02-04	Years 04-05	SES(α=0.9)	MA(2 month)
October	5	17	5	
November	5	19	5	
December	7	5	5	5
January	10		7	6
February	8		10	9
March	3		9	9
April	15		4	6
May	8		14	9
June	11		9	12
July	7		11	10
August	4		8	9
September	6		5	6
October	12		6	5
November	6		12	9
December	9		7	9
January	6		9	8
February	5		7	8
March	14		6	6
April	7		14	10
May	6		8	11
June	10		7	7
July	10		10	8
August	6		10	10
September	14		7	8
	Mean Square Error		21.958	18.545
	Standard deviation		2.771	1.918
	Variance		7.679	3.680
	Average		8.125	8.182

Figure 14 shows both methods compared with the original data. As it is shown SES model presents a similar path to the demand points; however, MA presents closer demand points with respect to the actual demand. The method that reports less variance is the MA.

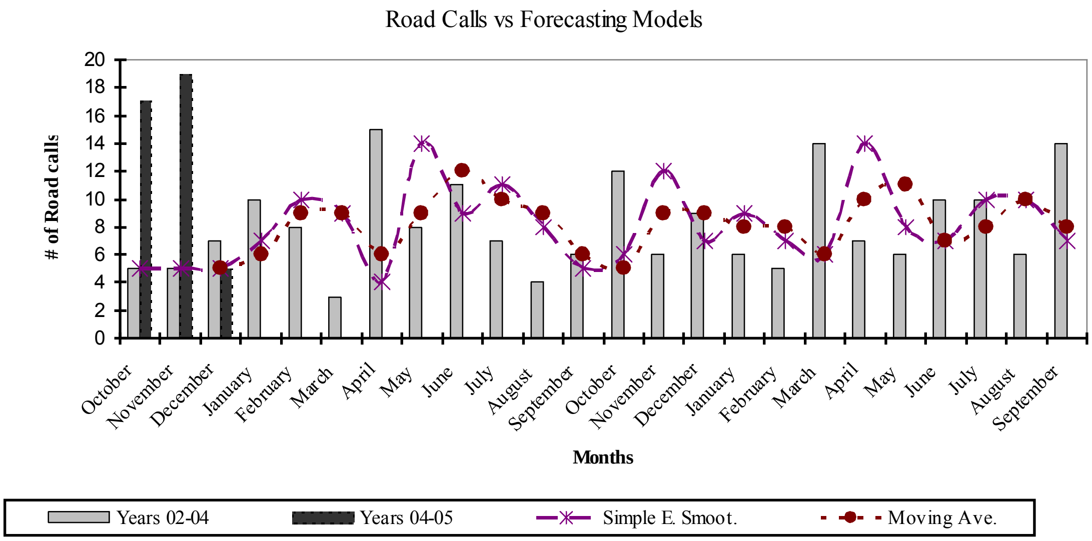

Figure 14: Actual Data vs. MA and SES for Brakes

RCs incidences due to brakes failure do not have consistency in terms of seasonality; therefore, the MA method presents an advantage over the SES due to the lower MSE. However, there are RCs incidences related to seasonal reasons which is the case for A/C failures. This particular system presents peaks of repair demand during the summer months. After applying the same analysis to the A/C demand, the two forecasting methods reported 91.2 MSE and 98 MSE for SES and MA respectively. However, the variance is very close showing 11.775 and 11.663 for SES and MA. Figure 15 shows the trend of demand for A/C failures from 2002 to 2004, as well as the two forecasting models applied. The bars represent the actual demand and the two lines represent the forecasting models.

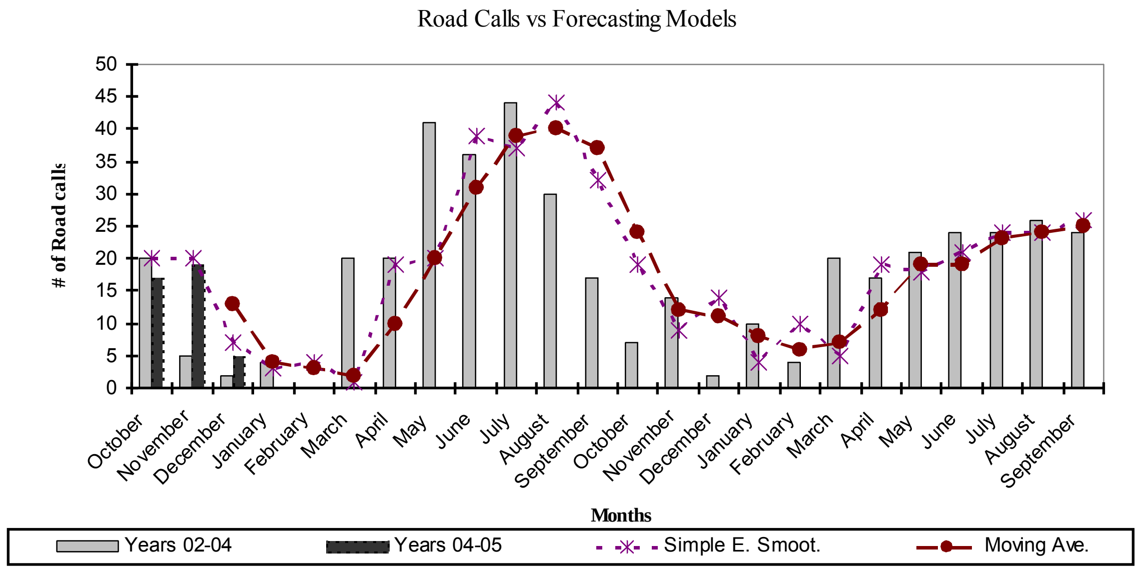

Figure 15: RCs vs. Forecasting Models for A/C System

Peaks of demand make that the high variation between close data points be smoothed resulting on giving the SES model as the most accurate estimator. However, the MA also presents close estimations that can be valid to model future A/C failure incidences. Due to the closest MSE and variances presented by the two methods, it is necessary to analyze with detail the best method to be applied. A test of hypothesis for the ratio of the two population variances is the used to evaluate the most accurate method.

The hypothesis testing is based on the *F* distribution presented as follow (Mendenhall, Sincich, 1995). The null hypothesis H_0 states that $S_{1\ (SES)}$ and $S_{2\ (moving\ average)}$ corresponding to the brakes system demand forecast are equal. The alternative hypothesis states that S1 > S_2 and therefore $S_{2\ (moving\ average)}$ is the most accurate method.

- H_0: $S_1 = S_2$ Null hypothesis

Where: S_1 and S_2 are the population variance for methods one and two

- N_1, N_2 are the sample sizes for methods one and two

- α is the level of confidence of T
- F_o is the test statistic

The alternative hypothesis and the criteria for acceptance and rejection are:

- $H_a = S_1 > S_2$ Reject if $F_o > F_\alpha$
- Degrees of freedom = 23 and 21 for populations N_1 and N_2
- Level of confidence $\alpha = 0.05$ $F_{0.05} = 2.06$

Table 5: Test of Hypothesis for the Variances of MA and SES

	Simple E. Smoothing	Moving Average
Mean	8.125	8.181818182
Variance	7.679347826	3.67965368
Observations	24	22
Df	23	21
F	2.086975703	
P(F<=f) one-tail	0.047439005	
F Critical one-tail	2.063280363	

The results shown in table 5 demonstrate that F_o value equal to 2.087 exceeds the tabulated value $F_{0.05}$ (2.06). Moreover, the *p* value calculated (0.04) is less than the maximum tolerated value that was stated for the test (0.05). As a result the null hypothesis should be rejected. However, there is not enough evidence to state that the MA method is more accurate than the SES method. To determine which method is more effective or if the two models have the same effectiveness, a test of the difference between the two population means is conducted.

- μ_1 and μ_2 represent the mean of the SES and MA forecast respectively.
- $H_0 : \mu_1 = \mu_2$
- $H_a: \mu_1 > \mu_2$

- The t distribution based on $n\text{-}1$ degrees of freedom is based on a sample of 22 months. The null hypothesis will be rejected if $t > t_{0.05}$ (1.721)

Table 6: t-Test: Paired Two Sample for Means (A/C Jobs)

	SES	MA
Mean	18.13636	17.68182
Variance	151.5519	136.0368
Observations	22	22
t Stat	0.515319	
P(T<=t) one-tail	0.305856	
t Critical one-tail	1.720743	

Since the value of the t statistic 0.515319 does not exceed the critical value $t_{0.05}$ 1.721, there is evidence at $\alpha = 0.05$ to show that the null hypothesis cannot be rejected. This conclusion can be also stated after analyzing the p-value of the test that shows a greater value 0.305856 than the α =0.05 level selected. As a result, it can be stated that the SES and MA forecasting methods are equal and therefore either of them can be used to predict repair jobs at transit facilities.

After evaluating the two methods with SES (α=0.9) and MA (2 month average), it is important to assess the optimal factor of smoothing in any of the methods to be applied. In this case a comparison between MA (4 months average) and MA (2 months average) is performed using a t-test on the difference between the two population means for RCs in A/C system.

- μ_1 and μ_2 represent the mean of the $MA_{(2\ \text{month average})}$ and $MA_{(4\ \text{month average})}$ forecasts respectively.
- The null hypothesis states that $\mu_1 = \mu_2$
- The alternative hypothesis states that $\mu_1 < \mu_2$

- The t distribution based on $n-1$ degrees of freedom is based on a sample of 20 months. The null hypothesis will be rejected if $t < -t_{0.05,19}$ (1.729)

Table 7: t-Test: Paired Two Sample for Means (MA)

	2 month ave.	*4month ave.*
Mean	18	18.6
Variance	107.0526316	138.4631579
Observations	20	20
Pearson Correlation	0.867184562	
Hypothesized Mean Difference	0	
df	19	
t Stat	-0.45777595	
P(T<=t) one-tail	0.326152644	
t Critical one-tail	1.729132792	

The value of the t statistic -0.4577 is not less than the negative value of $t_{0.05,19}$ 1.729, there is evidence at the 0.05 level of significance to show that the null hypothesis cannot be rejected and the moving average forecasting methods with 2 and 4 months average are equals for the type of demand studied. However, since the MSE_1 (98) < MSE_2 (183.85), the method that applies 2 months of average is recommended.

5.1 Forecasting Model Applied to Failure Incidences

Data from the historical record of incidences is used to model the future possible occurrences with MA (two months) method. The selected forecasting model is applied to real data that comes from the historical information of failure incidences at a transit facility. Table 8 presents a monthly forecasting model for engine failures on a period of one year.

Table 8: Possible Monthly Outcomes of Engine Repairs for Year 2005

Months	RCs - Engine System		Forecast
	Year 02-04	Year 04-05	MA (2-month)
October	23	21	
November	8	22	
December	18	15	16
January	14		13
February	15		16
March	19		15
April	18		17
May	20		19
June	19		19
July	19		20
August	12		19
September	16		16
October	17		14
November	15		17
December	13		16
January	9		14
February	26		11
March	21		18
April	15		24
May	16		18
June	7		16
July	23		12
August	19		15
September	27		21

MSE	31.545
S	2.211

After the data is analyzed, it can be noticed that for engine system, the months of December reported 18, 13 and 15 cases for years 2002, 2003, and 2004 respectively and the forecasted value was 16. If this method would have been used in December 2005, the department could have reacted effectively to the demand. This is an interesting case for this type of repairs since inventory related with engines is usually expensive and difficult to maintain.

The data is then plotted to visualize the reaction of the estimated data to the actual demand. Figure 16 presents the RCs for years 2002 to 2004 versus the forecasted demand by using MA. The bars represent the past demand and the RCs for the months 10, 11, and 12 of 2004. The line shows the reaction to the demand using MA (2-months averaged).

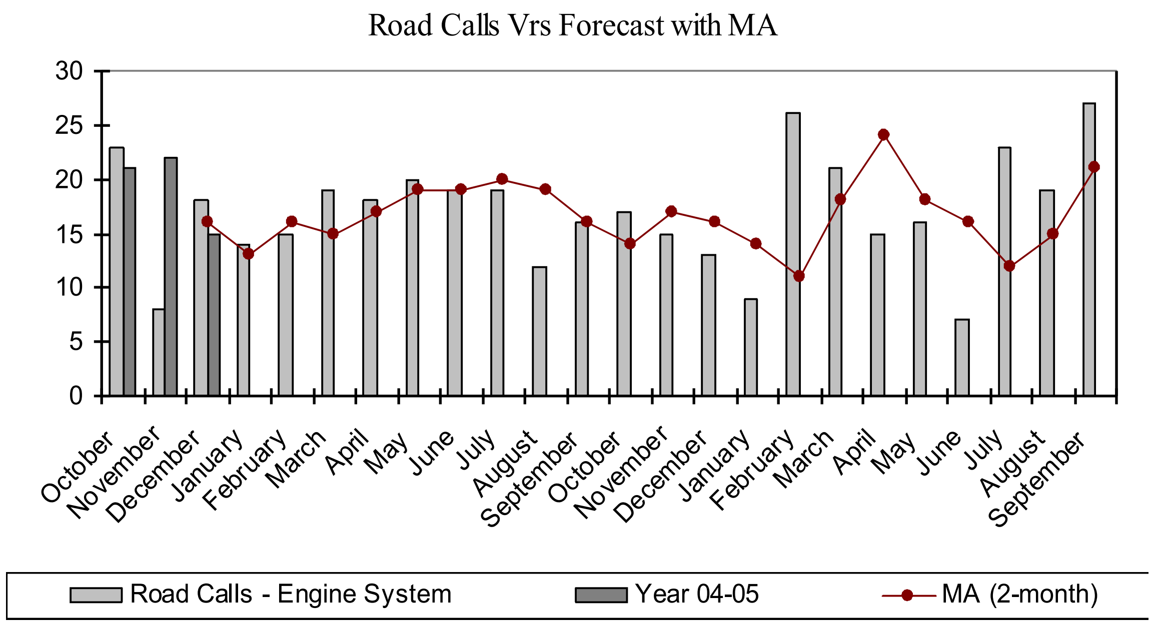

Figure 16: RCs (02-04) vs. Forecast with MA for Engine System

As it is shown in the graph, February 2003 presented an unusual peak of demand that was not closely marked by the model. However, it can be also seen that there is a rapid reaction to the demand presented for the majority of the year.

The forecasting developed would help managers to plan maintenance operations on a monthly basis. In this way, the facility can have parts in inventory before a breakdown occurs, thus buses will not stay idle for a long period of time. For example, by knowing the typical occurrence of engine breakdowns, the facility could keep a determine number of engines in stock or prepare providers on just in time delivery.

In the short time or daily basis, the modeling of repair occurrences could be useful to plan shifts in terms of labor needs, shop capacity and bays allocation. Forecasting and analyzing RCs is important for maintenance supervisors to get insights of how to improve preventive maintenance jobs. By using the PM time standards model, more tasks could be included in the process and some components could be replaced before they break and damage other associated components. For example, including an exhaustive A/C maintenance before summer time would reduce the high incidence of this type of breakdowns.

CHAPTER 6

THE SCHEDULING MODEL

In this study a mathematical scheduling model that considers a finite number of jobs, bays, and days is designed to allocate resources in transit maintenance facilities. The model takes into consideration repair jobs demand forecasted, the repair time standards and the technicians' performance level. Two levels of scheduling are suggested for the transit facilities: short time and long time horizon. In a short time horizon, maintenance supervisors allocate resources for a single shift on a day. In a long time horizon managers can use the scheduling to plan facility operations and make decisions ahead of time for a month period or a quarter. The next section describes in detail the model developed and its application for a short and long period of time.

6.1 Basic Model

The main objective of this scheduling model is to serve the maximum number of vehicles that require any type of repair. This model allocates the most qualified technicians (highest performance) to a required job. The performance level represents a dependable input variable that comes as a result of the repair time standards. The model also considers the repair time standards as a fundamental component when allocating buses to bays during a working shift. The scheduling model is as follows:

$$\text{MAX} \sum_{k=1}^{t} \sum_{i=1}^{b} P_{ik} X_{ik} \qquad (1)$$

Subject to:

$$\sum_{i=1}^{b} X_{ik} <= \mathrm{D}_k \qquad \forall\, k = 1..\, t \qquad (2)$$

$$\sum_{i=1}^{t} ST_k X_{ik} <= \mathrm{T}_i \qquad \forall\, i = 1..\, b \qquad (3)$$

$$\mathrm{X}_{ik} >= 0 \text{ and Integer} \quad (\text{for all } _i \text{ and } _k) \qquad (4)$$

Where:

- $X_{ik} = \begin{cases} 1, \text{ if the job } k \text{ is assigned to bay } i \\ 0, \text{ if the job } k \text{ is not assigned to bay } i \end{cases}$
- P_{ik} = performance level for technician i to do job k
- ST_k = standard time for job k
- D_k = total demand for job k during a shift
- b= Total number of bays available in the facility
- i = Bay index
- t = Total number of jobs performed at the facility (PM, brakes, engine, RCs, etc.)
- k = Job index
- T_i = Total time available per bay (it is usually set to 480 minutes)

Equation *(1)* represents the scheduling objective which is to maximize the number of jobs processed assigning the technicians with the highest performance level. Equation (*2)* represents the first constraint which corresponds to the demand based on the forecasting model or from the facility immediate needs. Constraint *(3)* accounts for the total time on a shift. Constraint *(4)* is the nonnegative condition for variable X.

6.2 Extended Model

The following extended model includes factors such as shifts and time horizon. The model is capable of scheduling different jobs for one-month period, considering three shifts, eight hours a day, and a maximum of 10 bays. The following notation is used:

- b= Total number of bays available in the facility
- i = Bay index
- s= Total number of shifts
- j = Shift index
- t = Total number of jobs performed at the facility (PM, brakes, engine, RCs, etc.)
- k = Job index
- d= Total number of service days at the facility
- l = Day index
- we= Total number of weeks to be scheduled in the time horizon
- m = Week index
- $X_{ijklm} = \begin{cases} 1, \text{ if the job is assigned to bay } i, \text{ shift } j, \text{ task } k, \text{ day } l, \text{ and week } m \\ 0, \text{ if the job is not assigned in bay } i, \text{ shift } j, \text{ task } k, \text{ day } l, \text{ and week } m \end{cases}$
- P_{ik} = the performance level for technician i to a job k
- ST_k = Standard time to perform a job "k"
- w_k = weight given to a job based on urgency of the repair completion (the higher the need, the higher the weight). If there is no preference w_k is equal to one.
- D_k = Demand of job "k"
- T_i = Total time available per bay (it is usually set to 480 minutes)

The formulation of the model is presented as follows:

$$\text{MAX} \quad \sum_{m=1}^{we}\sum_{l=1}^{d}\sum_{k=1}^{t}\sum_{j=1}^{s}\sum_{i=1}^{b} w_k P_{ik} X_{ijklm} \qquad (5)$$

Subject to:

$$\sum_{m=1}^{we}\sum_{l=1}^{d}\sum_{j=1}^{s}\sum_{i=1}^{b} X_{ijklm} <= D_k \qquad \forall\, k = 1..t \qquad (6)$$

$$\sum_{k=1}^{t} ST_k X_{ijklm} <= T_i \qquad \forall\, j = 1..s \qquad \forall\, l = 1..d \qquad \forall\, m = 1..w \qquad (7)$$

$$X_{ijklm} >= 0 \qquad \text{and Integer} \qquad (8)$$

The objective function *(5)* maximizes the number of buses served daily. P_{ik} represents the factor that maximizes the equation since technicians with the major performance level are assigned first before those who have low performance level. Variable w_k represents the weight given to a type of job that has priority on completion over the others.

The constraints are represented by the repair and inspection jobs needed during the time horizon should be accomplished in a daily basis. If the capacity is not enough to cover a higher demand, the jobs must be scheduled for the following shift or day. However, if the demand is low, the model still gives the maximum possible number of jobs that can be performed in the bay thus managers can react rapidly to unexpected repairs. This is reflected in constraint *(6)*. Constraint *(7)* evaluates the total number of jobs that can be allocated in each bay per shift depending upon the total hours worked per shift, the model allocates as many jobs as possible by using the repair standard times. Constraint *(8)* is nonnegative condition for variable X.

6.3 Heuristic Approach

The scheduling model takes advantage of the repair time standards to show the possible combination of jobs that can be allocated in a single shift. Since it is assumed that the transit facility has a shop for the repairs and a shop to perform the preventive maintenance, it is recommended that a specific type of jobs be performed in every shift.

From the results of the repair time standards, up to two brake jobs can be now served in one bay per shift. Moreover, one PM -12K job can be scheduled in bay per shift. However, the remaining time after the PM is performed is recommended to be used on process improvements or additional jobs.

For testing purposes, the time estimated for RC is set for 480 minutes since this kind of job requires going through a process of diagnosis and then the repair is performed. For the case of engine replacement, the time assigned is 480 minutes since these jobs take approximately two days to be completed. The possible combinations of service are found with a simple scheduling approach and put in the IMIS.

Computational complexities related with the high number of variables and the optimal model requires the development of a heuristic approach. This section presents the algorithm developed to solve the scheduling model. It is based on the selection of jobs to be distributed as well as on the selection of bays available to allocate the buses. The model flow and algorithm are presented as follows:

- Initialize variables.
  Set b = 1…10; tb = 480; k = 1 = RCs, 2 = engine replacement, 3 = brakes; i = 1..10; p_{ik} denotes the performance level for technician i in job k; st_k is the standard time for job k; d_k is the demand for job k; and t_i is the total time available in bay i.

- If demand of job 3 is greater or equal than 16 and demand of job 1 is greater than 1 then find the maximum performance level of technicians in job 1.
  If the time in bay where the technician is found is equal to the total bay time, then assign the job 1 to the bay and technician i.
  Subtract one job 1 from demand of job 1.
  If the time of bay i becomes zero then the bay is full and no more jobs can be assigned to it.

- If demand of job 3 is greater or equal than 16 and demand of job 2 is greater than 1 then find the maximum performance level of technicians in job 2.
  If the time in bay where the technician is found is equal to the total bay time, then assign the job 2 to the bay and technician i.
  Subtract one job 2 from demand of job 2.
  If the time of bay i becomes zero then the bay is full and no more jobs can be assigned to it.

- Start the cycle to assign brake jobs. Repeat it while there are still available bays or there is demand for job 3.
  Find the maximum performance level of technicians in job 3.
  Assign the job 3 to the bay and technician i. Subtract one job 2 from demand of job 2.
  Subtract the standard time for job 3 from the time available in bay i.
  If the number of job 3 assigned to bay i is equal to 2 or the demand of job 3 is 0, then no more jobs can be assigned to bay i.

- Start the cycle to assign remaining jobs type 1 and 2.
  If demand of job 3 is equal to zero, and there is still demand for job 1, then find the maximum performance level of technicians in job 1.
  If the time in bay where the technician is found is equal to the total bay time, then assign the job 1 to the bay and technician i.
  Subtract one job 1 from demand of job 1.
  If the time of bay i becomes zero then the bay is full and no more jobs can be assigned to it.
  If demand of job 3 is equal to zero, and there is still demand for job 2, then find the maximum performance level of technicians in job 2.
  If the time in bay where the technician is found is equal to the total bay time, then assign the job 2 to the bay and technician i.
  Subtract one job 2 from demand of job 2.
  If the time of bay i becomes zero then the bay is full and no more jobs can be assigned to it.

6.4 Model Testing and Results

The model is tested using a scenario of scheduling for RCs, engine replacement, and brakes. The standard time developed for brakes is 182 minutes, the engine replacement time would be 480 minutes, and the stipulated time for RCs is 480 minutes. Some other assumptions are necessary to test the model. For example: at least one technician will correspond to a working bay and each of them will be assigned to the same bay everyday. This assignment would facilitate the allocation of fixed working places for technicians. The demand comes either from the forecasted data or from demand received during the day.

The possible outputs can be applied to any required day or shift depending upon the demand presented. The capacity of the shop is set for ten bays within a shift of 8 hours. The heuristic approach assigns at least one RC and one engine job if the brakes demand exceeds 16 jobs. In this way, at least 8 bays are assigned to brakes and one bay for a RC and one for an engine replacement. This assignment facilitates the allocation of higher number of minor repairs to prevent major breakdowns.

The algorithm was coded in Matlab version 7.0 (See Appendix 1). The outputs for a shift with the simulation of different demands are shown below.

General data Input:

- Total time per shift = 480 minutes
- Standard time for brakes = 182 minutes
- Time for engine replacement= 480 minutes
- Time for RCs jobs = 480 minutes
- Number of bays = 10
- Number of technicians = 10
- Performance level = classification according to the technicians' actual performance. It is shown in table 6 and the number of significance is:
    - 0.9: below the standard (actual performance <= 94%)

- 1.0: on the standard (95% <= actual performance <= 104%)
- 1.1: above the standard (actual performance >= 105%)

Table 9: Performance Rating for Technician i on Job k

Job	1	2	3	4	5	6	7	8	9	10
RC	0.9	1.1	1.0	1.0	0.9	1.1	0.9	1.0	0.9	1.0
ENG	1.0	1.1	0.9	1.1	1.0	0.9	1.0	1.1	1.0	0.9
BRK	1.1	0.9	1.0	0.9	1.1	1.0	1.1	0.9	1.1	1.1

The scenarios of demand and distribution are shown in the following tables. They reflect a distribution of jobs based on giving priority to the most frequent jobs and to those with the lowest standard time. However, if the demand of jobs with the lowest standard time exceeds the capacity, at least one less frequent job and with highest standard time will be allocated if demand exists. For example, if the demand of brakes jobs exceeds 16, this means that the shift resources would be covered only with brakes jobs. However, if there is at least one job required for engine or RCs, the system will assign the technicians with the highest performance level on RC and engine to each bus and bay. After that assignment is done, the brakes repairs are allocated in the remaining bays. Scenario 1 of assignment presented in table 10 shows the distribution resulted for a demand of 4 RC, 2 engine replacement and 10 brakes.

Table 10: Outcomes of the Objective Function for Scenario 1

	Number of jobs allocated per bay									
Jobs	1	2	3	4	5	6	7	8	9	10
RC	0	1	1	0	0	1	0	0	0	0
ENG	0	0	0	1	0	0	0	1	0	0
BRK	2	0	0	0	2	0	2	0	2	2

Similarly the outcomes for constraint 6 (demand) are presented as follow:

- Road calls demand and assigning → $X_1 = 3 <= D_1 = 4$
- Engine demand and assigning → $X_2 = 2 <= D_2 = 2$
- Brakes demand and assigning → $X_3 = 10 <= D_3 = 10$

The outcomes for constraint 7 (time per shift) are shown in table 11.

Table 11: Outcomes for Constraint 7 – Scenario 1

	Utilization time per bay (minutes)									
Jobs	1	2	3	4	5	6	7	8	9	10
RC		451	480			455				
ENG				455				455		
BRK	342				348		348		348	348

Scenario 2 shows the distribution that will satisfy a demand that exceeds the 16 brakes and assign first one engine and one RC and then the maximum number of brakes that could be allocated. This scenario responds to a demand of 4 RC, 5 engine replacement and 17 brakes. The outcomes of the objective function are presented in table 12 as follows:

Table 12: Outcomes of the Objective Function for Scenario 2

	Number of jobs allocated per bay									
System	1	2	3	4	5	6	7	8	9	10
RC	0	1	0	0	0	0	0	0	0	0
ENG	0	0	0	1	0	0	0	0	0	0
BRK	2	0	2	0	2	2	2	2	2	2

The outcomes for constraint 6 (demand) are presented as follow:

- Road calls demand and assigning → X1 = 1 <= D1 = 4

- Engine demand and assigning ➔ X2 = 1 <= D2 = 5
- Brakes demand and assigning ➔ X3 = 16 <= D3 = 17

The technician's performance level is not only the factor that permits the maximization of the number of jobs to be performed but also improves productivity in terms of completion time. The outcomes for constraint 7 (time per shift) are shown in table 13 and demonstrate how the assignment of technicians with the highest performance level enhances the time available in the bay to improve the processes or have the bay clear to unexpected needs.

Table 13: Outcomes for Constraint 7 – Scenario 2

	Utilization time per bay									
Systems	1	2	3	4	5	6	7	8	9	10
RC		455								
ENG				455						
BRK	348		364		348	364	348	384	348	348

The third scenario represents the case when the demand exceeds the capacity of a shift. For this case 30 brakes repairs, 20 engines and 20 road calls need to be scheduled. Given that brake repair takes much less time than engines or road calls, the maximum number of brakes should be scheduled but without disregarding the other type of jobs. For that reason, brakes are assigned to 16 bays (2 jobs to 8 bays) and to the other two bays one engine and one road calls jobs are assigned.) The unsatisfied demand would be scheduled similarly in the following day by using the same distribution of jobs. Table 14 presents the allocation of jobs for every shift.

Table 14: Outcomes of the Objective Function for Scenario 3

	Number of jobs allocated per bay									
System	1	2	3	4	5	6	7	8	9	10
RC	0	1	0	0	0	0	0	0	0	0
ENG	0	0	0	1	0	0	0	0	0	0
BRK	2	0	2	0	2	2	2	2	2	2

The outcomes for constraint 6 (demand) in scenario 3 are presented as follow:

- Road calls demand and assigning ➔ $X_1 = 1 <= D_1 = 20$
- Engine demand and assigning ➔ $X_2 = 1 <= D_2 = 20$
- Brakes demand and assigning ➔ $X_3 = 16 <= D_3 = 30$

The outcomes for constraint 7 (time per shift) are shown in table 15.

Table 15: Outcomes for Constraint 7 – Scenario 3

	Utilization time per bay									
Systems	1	2	3	4	5	6	7	8	9	10
RC		455								
ENG				455						
BRK	348		364		348	364	348	384	348	348

Scenario 2 and 3 presented a similar distribution due to the existence of engine and RC demand and brakes repair requirement greater than the number of bays. Scenario 4 presents no brakes demand and a high requirement of engine and RC jobs. In this case the jobs are distributed on a 50%-50% basis. The demand for this scenario is 30 jobs for engine and RC respectively.

Table 16: Outcomes of the Objective Function for Scenario 4

	Number of jobs allocated per bay									
System	1	2	3	4	5	6	7	8	9	10
RC	0	1	1	0	0	1	1	0	0	1
ENG	1	0	0	1	1	0	0	1	1	0
BRK	0	0	0	0	0	0	0	0	0	0

The outcomes for constraint 6 (demand) in scenario 3 are presented as follow:

- Road calls demand and assigning ➔ $X_1 = 5 <= D_1 = 30$
- Engine demand and assigning ➔ $X_2 = 5 <= D_2 = 30$
- Brakes demand and assigning ➔ $X_3 = 0 <= D_3 = 0$

The outcomes for constraint 7 (time per shift) are shown in table 17.

Table 17: Outcomes for Constraint 7 – Scenario 4

	Utilization time per bay									
Systems	1	2	3	4	5	6	7	8	9	10
RC		455	480			455	509			480
ENG	480			455	480			455	480	
BRK										

The system provides options of bus allocation that can be used to plan maintenance schedules in a daily basis. The database is configured with the scenarios generated that will assist supervisors in the decision making process.

6.5 Productivity Measurement

The scheduling performance is measured based on the productivity improvement of the maintenance facility. The quantity of jobs that can be allocated with the integrated scheduling model are compared and tested against the current method to demonstrate improvement in utilization and productivity, and effectiveness when assigning technicians according to their performance level to the required tasks.

The current method of scheduling is based on the average completion time calculated in the repair time standards study. This time is rounded to 240 minutes and although it seems like two jobs can be allocated, only one job is actually assigned per shift due to the lack of consistency in completion time. Some technicians may take less than the 240 minutes and some may take much more time to complete the job. On the other hand, the time standard developed suggests 182 minutes per job, enough time to complete two jobs per bay. Table 18 shows the comparison of the percentage of utilization per bay when allocating brake jobs. The productivity improvement is noticed when the demand of jobs exceeds the capacity of the facility.

Figure 17 shows the productivity improvement from a random distribution of brake jobs to be scheduled shown in table 18. This figure shows the difference between the number of jobs that can be accomplished by following the current method (with only one job assigned per bay), versus the new method that permits the allocation of two brake jobs per bay. Moreover, the assigning of two jobs still presents some time remaining that could be used either to allocate a job with small completion time or to improve the current repair process.

Table 18: Percentage of Utilization per Bay – Current Scheduling

Demand of buses per day	Current number of jobs scheduled		Maximum possible jobs with new model			
	# of jobs	Productivity	# of jobs	Productivity PL 90	Productivity PL 100	Productivity PL110
15	10	38%	15	53%	57%	60%
20	10	38%	20	71%	76%	80%
8	8	30%	8	29%	30%	32%
5	5	19%	5	18%	19%	20%
18	10	38%	18	64%	68%	72%
22	10	38%	20	71%	76%	80%
17	10	38%	17	61%	64%	68%
30	10	38%	20	71%	76%	80%
25	10	38%	20	71%	76%	80%
2	2	8%	2	7%	8%	8%
10	10	38%	10	36%	38%	40%
7	7	27%	7	25%	27%	28%
16	10	38%	16	57%	61%	64%
28	10	38%	20	71%	76%	80%
24	10	38%	20	71%	76%	80%
Media	8.8	33%	14.53	52%	55%	58%

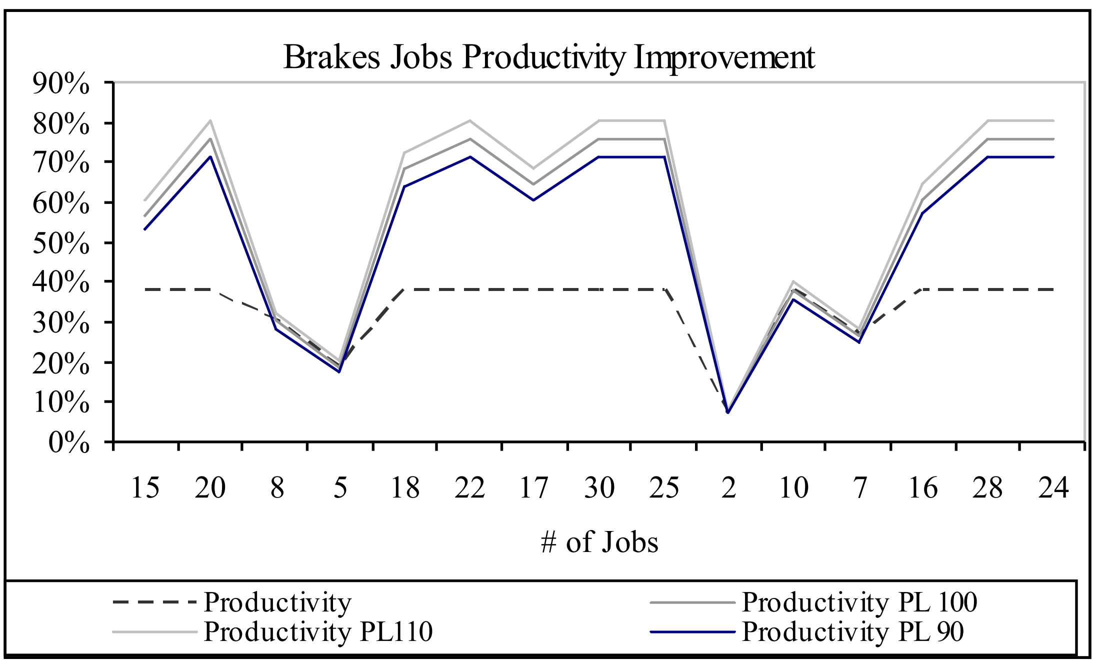

Figure 17: Productivity Improvement – Brake Jobs

CHAPTER 7

THE INTEGRATED MAINTENANCE INFORMATION SYSTEM

In this chapter, the database development is presented and the models are applied to a typical transit maintenance facility. The current situation related to repair time standards, forecasting, and scheduling is discussed and then compared with the proposed model.

7.1 Database Specifications

The database development was performed in parallel to the systems/models development. The IMIS gathers the information from the models developed, and serves as for a planning tool. It is designed and run in Microsoft Access® for the benefit of the final users since it is a software easily available commercially. The database designed for the repair time standards research is the base for the development of the IMIS.

The database has the information stored in tables represented by “employee”, “vehicle”, “system”, “shift”, “daily schedule”, “work order”, among others. For each table there are a number of entities that gives characteristics to the type of information stored. Each entity has a name, data type and description. Figure 18 shows the table “employee” with its entities represented by fields, type and description.

Field Name	Data Type	
employeeID	Number	Technician's Identification Number
name	Text	Technician's Given Name
address	Text	Technician's Home Address
city	Text	Technician's Home City
stateid	Text	Technician's State of residency
zip	Text	Technician's Home Zip Code
phone	Text	Technician's Phone Number
department	Text	Technician's Department & Area
company	Text	Technician's Company Name
systemcode1	Text	Technician First Job Assigned
skillttype1	Text	Techncian's skill in Firts job Assigned
systemcode2	Text	Technician Second Job Assigned
skillttype2	Text	Techncian's skill in Second job Assigned
systemcode3	Text	Technician Third Job Assigned
skillttype3	Text	Techncian's skill in Third job Assigned
shiftdescription	Number	Shift in which the technician is working

Figure 18: Table Employee – Fields, Data Types and Description

A relational database facilitates the interaction between any two tables. Establishing connection among tables eliminates data redundancy and ensures confidence when accessing data. The relationships can be classified into one-to-one, one-to-many, many-to-many, or no relation depending upon the type of data shared by the tables and the characteristics of the fields shared.

Figure 19 shows the architecture of the table relationship of the IMIS. As it is seen in the figure, most of the tables have correlative relation with the employee table. Tables that are linked to work orders have a relation with employee automatically.

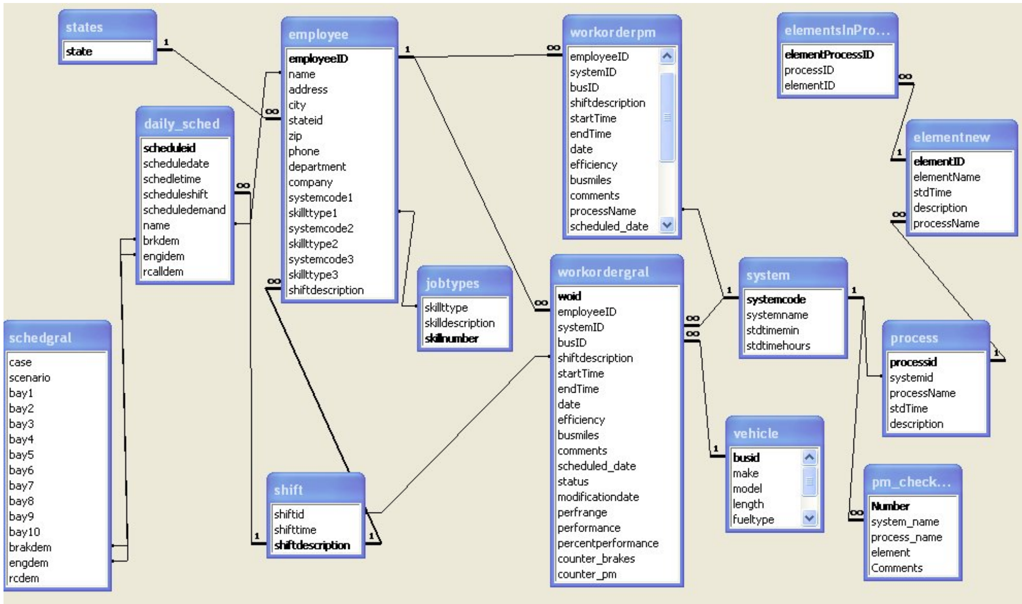

Figure 19: Table-Relationship Diagram

7.1.1 Database tables: In this section the most relevant tables are discussed. This includes information regarding employee, vehicle, system, process, daily schedule and work order. All the information entered into the system through a form is stored in the corresponding tables as it is shown in figure 20.

File Edit View Insert Format Records Tools Window Help

employeeI[	name	address	city	stateid	zip	phone	department	company	systemcode1	skilltype1	systemcod
102	Mary Fisher	1234 Residence Street	Home	Fl	54321-	(098) 765-4321	Maintenance	Hartline	Brakes	A	AC
103	John Smith	4120 Fletcher Av	Tampa	Fl	33546-	(137) 856-8761	Maintenance	Hartline	Brakes	A	Road Call
104	Peter Louis	3312 West	Tampa	Fl	33123-	(813) 987-6541	Maintenance	Hartline	Brakes	M	Engine
105	Adam Sandler	1789 Bridle Dr	Tampa	Fl	33710-	(813) 786-5432	Maintenance	Hartline	Brakes	M	pm12k
106	Jim Miller	4533 Fowler	Tampa	Fl	33124-	(813) 654-3333	Maintenance	Hartline	Road Call	A	Brakes
107	Hardy Green	Excellence Blvd	Tampa	Fl	23345-	(813) 985-9246	Maintenance	Hartline	Road Call	A	Brakes
108	Kevin Baker	Campus Walk	Tampa	Fl	33232-	(813) 215-7753	Maintenance	Hartline	Road Call	B	Engine
109	Kara Willis	1234 Residence Street	Home	Fl	54321-	(098) 765-4321	Maintenance	Hartline	Road Call	A	AC
110	David Smith	4120 Fletcher Av	Tampa	Fl	33546-	(137) 856-8761	Maintenance	Hartline	Road Call	A	Brakes
111	Bonnie Raimes	3312 West	Tampa	Fl	33123-	(813) 987-6541	Maintenance	Hartline	Road Call	B	Brakes
112	Maura Ridson	1789 Bridle Dr	Tampa	Fl	33710-	(813) 786-5432	Maintenance	Hartline	Road Call	B	Engine
113	Kevin Lowe	4533 Fowler	Tampa	Fl	33124-	(813) 654-3333	Maintenance	Hartline	Engine	M	pm12k
114	Rob Luce	Excellence Blvd	Tampa	Fl	23345-	(813) 985-9246	Maintenance	Hartline	Engine	M	pm12k
115	Deborah Wood	Campus Walk	Tampa	Fl	33232-	(813) 215-7753	Maintenance	Hartline	Engine	A	pm12k
116	Judy Woodland	1234 Residence Street	Home	Fl	54321-	(098) 765-4321	Maintenance	Hartline	Engine	B	AC
117	Gilbert Seward	4120 Fletcher Av	Tampa	Fl	33534-0000	(137) 856-8761	Maintenance	Hartline	pm12k	A	AC
118	Michael Peterson	3312 West	Tampa	Fl	33123-	(813) 987-6541	Maintenance	Hartline	pm12k	A	AC
119	Julie Taylor	1789 Bridle Dr	Tampa	Fl	33710-	(813) 786-5432	Maintenance	Hartline	pm12k	A	AC
120	Janée Martin	4533 Fowler	Tampa	Fl	33124-0000	(813) 654-3333	Maintenance	Hartline	pm12k	B	Brakes
121	Steve Polak	Excellence Blvd	Tampa	Fl	23345-	(813) 985-9246	Maintenance	Hartline	pm12k	A	Brakes
122	Charles Wolf	Campus Walk	Tampa	Fl	33232-0000	(813) 215-7753	Maintenance	Hartline	pm12k	A	Brakes
123	Paul Mitchell	1234 Residence Street	Home	Fl	54321-	(098) 765-4321	Maintenance	Hartline	pm12k	A	Brakes
124	Darren Fink	4120 Shire CT	Tampa	Fl	33546-	(137) 856-8761	Maintenance	Hartline	pm12k	A	Road Call
300	John Gilberth	1234 Fletcher Av	Tampa	Fl	33444-5555	(813) 777-7777	Maintenance	Hartline	pm12k	A	Road Call
0							Maintenance				

Figure 20: Information Stored in Table “Employee”

Other relevant tables in which data are manipulated include: vehicle, system, daily schedule, and work order. Table 19 shows the fields and content of table system. This table is important for the IMIS because it contains the standard time for each job. The standard time for brake repairs and PM (12K) where developed following the methodology presented in chapter 4.

Table 19: Table System

systemcode	systemname	stdtimemin	stdtimehours
Brake	Brake	182	3 Hours 2 Min
PM (12k)	PM	251	4 Hours 11 Min

Table 20 corresponds to the data that identify the vehicles. This information pertains to the buses observed during repair time standards study.

Table 20: Table Vehicle

busid	make	model	length	fueltype	startMiles	details
2001	Flexible	3454	40 Foot	Diesel	0	
2002	Flexible	C1221 1994	40 Foot	LPG	0	
2003	Flexible	3454	40 Foot	Diesel	0	
9603	Gillig	Phantom	40 Foot	Diesel	0	
9604	Gillig	Phantom	40 Foot	Diesel	0	
9605	Gillig	Phantom	40 Foot	Diesel	0	
9701	Gillig	Phantom	40 Foot	Diesel	0	
9702	Gillig	Phantom	40 Foot	Diesel	0	
9703	Gillig	Phantom	40 Foot	Diesel	0	
9801	Gillig	XT 1400 MAY 2000	40 Foot	Diesel	0	

Table 21 shows the daily schedule table and how the system stores information about the current or forecasted demand as well as the shift and the person who developed the scheduling.

Table 21: Table Daily Schedule

scheduleid	scheduledate	scheduleshift	scheduledemand	name	brkdem	engidem	rcalldem	brkdem2	brkdem1	engidem2	engidem1	Rcalldem2	Rcalldem1
14	3/3/2005	Morning	10	Gilbert Seward	5	2	3						
15	3/3/2005	Night	17	Gilbert Seward	13	2	2						
16	3/10/2005	Afternoon	46	Adam Sandler	10	32	4	10	10	55	10	3	4
17	3/10/2005	Afternoon	7	Charles Wolf	2	2	3	3	2	1	2	2	4

As it is seen in the table, jobs with schedule id 14 and 15 (shown in column 1) represent an input of current demand. In other words, no previous demand was entered therefore the demand is not forecasted. On the other hand, jobs with schedule id 16 and 17 (shown in column 1) have a total demand (see brkdem, engidem, and rcalldem fields shown in columns 6, 7, and 8) forecasted by using previous data.

7.1.2 Database input forms: The interface system-user is one of the most important components in a computerized system. Users should be able to enter the information in a straightforward way. In this section, three of the most relevant forms in which the information is managed are discussed, the “employee data input” form, the “daily schedule” form, and the “work order” form.

The “employee data” form is used to input basic data into the system. It requires basic information of the vehicle, system, and process. Figure 21 presents an example of the interface of the IMIS.

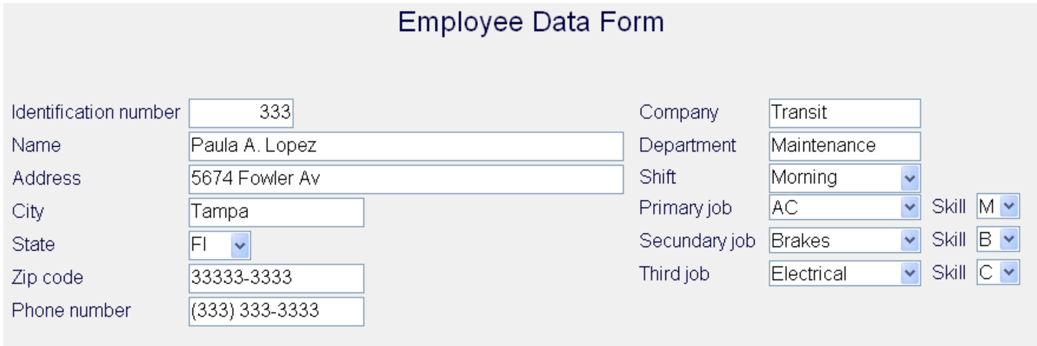

Figure 21: Employee Data Form

Planning the scheduling is one of the most important applications of the IMIS. The form "daily schedule" is intended to facilitate this process to the supervisors. This form gives the users the option of entering current data or forecasting possible situations. Users also are required to input the name of the person who prepares the schedule as well as the shift for which the schedule is done. Figure 22 shows the screen for scheduling input.

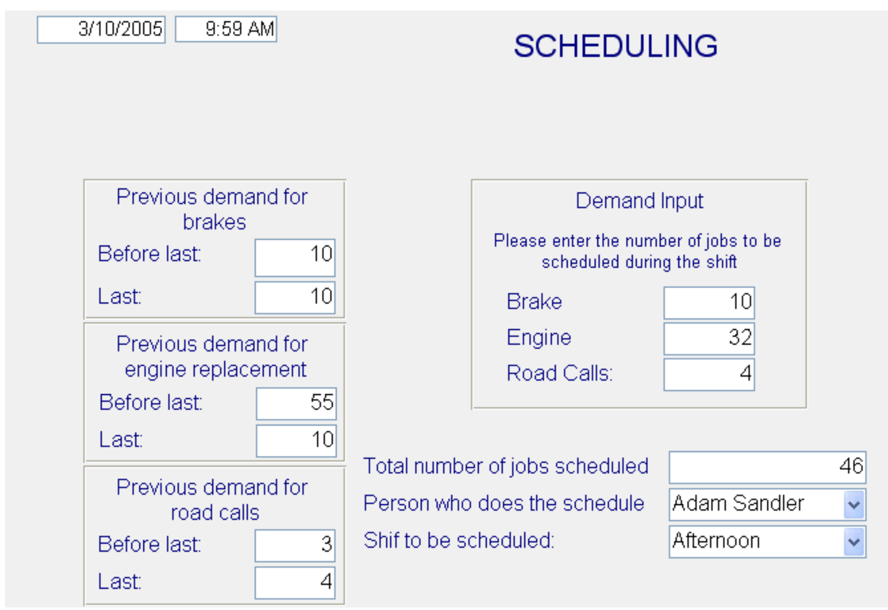

Figure 22: Daily Scheduling Form

The form "work order" is the interface to input information regarding jobs done. Technicians or supervisors are required to input the starting and ending time for the job to calculate the technician's performance level and also to records the maintenance history. Figure 23 shows the screen for work order input.

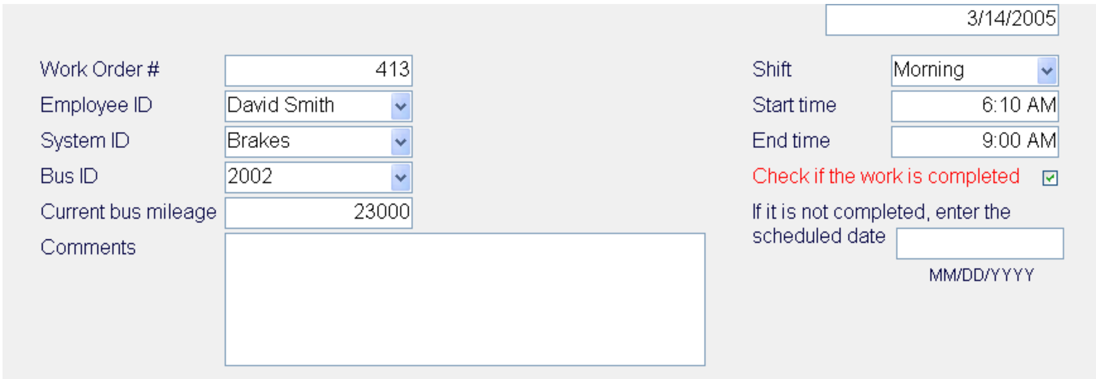

Figure 23: Work Order Form

7.2 Application

The example discussed represents a public transit organization that serves a middle type of city and population in the state of Florida. This includes an average population of 3,000,000 in the area and approximately 20% of this population is served by the public transit service. The company operates with 200 diesel buses and approximately another 120 vehicles that connect services with the buses.

Historical data regarding maintenance tasks incidence is analyzed to forecast a feasible path of jobs demand. This is mostly applied to those jobs that are very difficult to forecast due to the uncertain demand, e.g., RCs. Jobs such as PM, engine and transmission repairs are basically scheduled based on mileage intervals, therefore are less difficult to predict. To forecast demand of maintenance jobs is the main goal for designing the scheduling model, considering availability of bays, technician's skills and the deadline for the repairs.

Most transit facilities have fixed routes and their vehicles operate on predetermined timetables. This facilitates the forecasting of certain repair jobs and bus maintenance. This research shows a scheduling model that combines PM and brake time standards with forecasting information to allocate buses for repair in an eight-hour shift. By integrating the scheduling model with time standardization, transit maintenance shops can optimize resource utilization and improve the response capacity to unexpected breakdowns.

The transit facility studied does not use time standards to schedule resources; therefore, it is capable of allocating only one job per bay per shift no matter what the total time of the job is. If the technician is not able to finish the job during the shift he has the option of parking the bus aside to leave the bay empty for the next shift or he has the option of transferring the work order to the technician of the following shift.

Our study shows that based on the repair time standards for brake jobs, up to two brake jobs could be allocated to a bay and technician in a single shift. Also, one PM (12K) can be allocated in a bay and the remaining time can be used to improve maintenance processes or to allocate a shorter PM depending upon the service needs. Road calls and engine replacement standards are under development, but 480 minutes have been assumed and inputted into the database.

The modeling of forecasted demand is evaluated in Chapter 5 with data for a month period. This information can be also used by supervisors to estimate the demand for subsequent shifts.

The scheduling model is used as a tool to find the possible combinations of jobs to be allocated per shift. All the scenarios that resulted from the combination of PM jobs, RC, engine replacement, and brake repairs are included in the database.

The Integrated Maintenance Information System assists maintenance supervisors when evaluating workforce productivity and identifying needs of training. Therefore, some of the most important reports generated by the database are related to the performance level rate. With these reports, users can opt to obtain information as a list or as a graph. Figure 24 shows the graphical format report for a combined performance level of brake repairs and PM jobs. It shows the performance level grouped in three categories, below standard, standard, and above standard. The performance level report gives the managers a general idea of how the technicians are performing in comparison to the standards. The system also gives a listed report that specifies the actual performance per job and technician which is summarized in the graphical report. The performance level generated from the time standards is used to generate a report with the list of the technicians with their respective performance level in every shift.

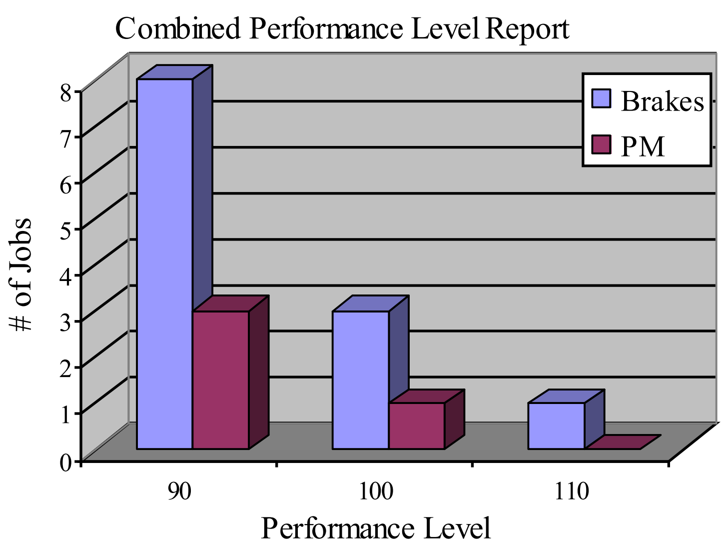

Figure 24: Graphical Report for Performance Level (Brake and PM Jobs)

The possible combinations of job allocation is also included in the database to facilitate the decision making process for supervisors at every shift. Figure 25 shows a partial list of job combinations that are included in the system. The scenario is based on the distribution of brake jobs, road calls, and engine replacement. These combinations distributed by technician's performance level were discussed in detail in Chapter 6.

case	scenario	bay1	bay2	bay3	bay4	bay5	bay6	bay7	bay8	bay9	bay10	brakdem	engdem	rcdem
266	1 Engine, 1 Road Call, 1 Brakes	1E	1RC	1B	0	0	0	0	0	0	0	1	1	1
267	2 Engine, 1 Road Call, 1 Brakes	1E	1E	1RC	1B	0	0	0	0	0	0	1	2	1
268	3 Engine, 1 Road Call, 1 Brakes	1E	1E	1E	1RC	1B	0	0	0	0	0	1	3	1
269	4 Engine, 1 Road Call, 1 Brakes	1E	1E	1E	1E	1RC	1B	0	0	0	0	1	4	1
270	5 Engine, 1 Road Call, 1 Brakes	1E	1E	1E	1E	1E	1RC	1B	0	0	0	1	5	1
271	6 Engine, 1 Road Call, 1 Brakes	1E	1E	1E	1E	1E	1E	1RC	1B	0	0	1	6	1
272	7 Engine, 1 Road Call, 1 Brakes	1E	1E	1E	1E	1E	1E	1E	1RC	1B	0	1	7	1
273	8 Engine, 1 Road Call, 1 Brakes	1E	1E	1E	1E	1E	1E	1E	1E	1RC	1B	1	8	1
274	1 Engine, 2 Road Call, 1 Brakes	1E	1RC	1RC	1B	0	0	0	0	0	0	1	1	2
275	2 Engine, 2 Road Call, 1 Brakes	1E	1E	1RC	1RC	1B	0	0	0	0	0	1	2	2
276	3 Engine, 2 Road Call, 1 Brakes	1E	1E	1E	1RC	1RC	1B	0	0	0	0	1	3	2
277	4 Engine, 2 Road Call, 1 Brakes	1E	1E	1E	1E	1RC	1RC	1B	0	0	0	1	4	2
278	5 Engine, 2 Road Call, 1 Brakes	1E	1E	1E	1E	1E	1RC	1RC	1B	0	0	1	5	2
279	6 Engine, 2 Road Call, 1 Brakes	1E	1E	1E	1E	1E	1E	1RC	1RC	1B	0	1	6	2
280	7 Engine, 2 Road Call, 1 Brakes	1E	1E	1E	1E	1E	1E	1E	1RC	1RC	1B	1	7	2
281	1 Engine, 3 Road Call, 1 Brakes	1E	1RC	1RC	1RC	1B	0	0	0	0	0	1	1	3
282	2 Engine, 3 Road Call, 1 Brakes	1E	1E	1RC	1RC	1RC	1B	0	0	0	0	1	2	3
283	3 Engine, 3 Road Call, 1 Brakes	1E	1E	1E	1RC	1RC	1RC	1B	0	0	0	1	3	3
284	4 Engine, 3 Road Call, 1 Brakes	1E	1E	1E	1E	1RC	1RC	1RC	1B	0	0	1	4	3
285	5 Engine, 3 Road Call, 1 Brakes	1E	1E	1E	1E	1E	1RC	1RC	1RC	1B	0	1	5	3
286	6 Engine, 3 Road Call, 1 Brakes	1E	1E	1E	1E	1E	1E	1RC	1RC	1RC	1B	1	6	3
287	1 Engine, 4 Road Call, 1 Brakes	1E	1RC	1RC	1RC	1RC	1B	0	0	0	0	1	1	4
288	2 Engine, 4 Road Call, 1 Brakes	1E	1E	1RC	1RC	1RC	1RC	1B	0	0	0	1	2	4
289	3 Engine, 4 Road Call, 1 Brakes	1E	1E	1E	1RC	1RC	1RC	1RC	1B	0	0	1	3	4
290	4 Engine, 4 Road Call, 1 Brakes	1E	1E	1E	1E	1RC	1RC	1RC	1RC	1B	0	1	4	4
291	5 Engine, 4 Road Call, 1 Brakes	1E	1E	1E	1E	1E	1RC	1RC	1RC	1RC	1B	1	5	4
292	1 Engine, 5 Road Call, 1 Brakes	1E	1RC	1RC	1RC	1RC	1RC	1B	0	0	0	1	1	5
293	2 Engine, 5 Road Call, 1 Brakes	1E	1E	1RC	1RC	1RC	1RC	1RC	1B	0	0	1	2	5
294	3 Engine, 5 Road Call, 1 Brakes	1E	1E	1E	1RC	1RC	1RC	1RC	1RC	1B	0	1	3	5
295	4 Engine, 5 Road Call, 1 Brakes	1E	1E	1E	1E	1RC	1RC	1RC	1RC	1RC	1B	1	4	5
296	1 Engine, 6 Road Call, 1 Brakes	1E	1RC	1RC	1RC	1RC	1RC	1RC	1B	0	0	1	1	6
297	2 Engine, 6 Road Call, 1 Brakes	1E	1E	1RC	1RC	1RC	1RC	1RC	1RC	1B	0	1	2	6
298	3 Engine, 6 Road Call, 1 Brakes	1E	1E	1E	1RC	1RC	1RC	1RC	1RC	1RC	1B	1	3	6

Figure 25: Scenarios of Scheduling Based on Standard Times

With the system supervisors will be able to input information regarding jobs demand. Reports that show the possible distribution of jobs and the list of technicians available for the shift with their respective performance level are then generated. Figure 26 shows the system interface used by supervisors to input the demand per shift. A list of technicians available for the shift and their respective skills type can be printed for records.

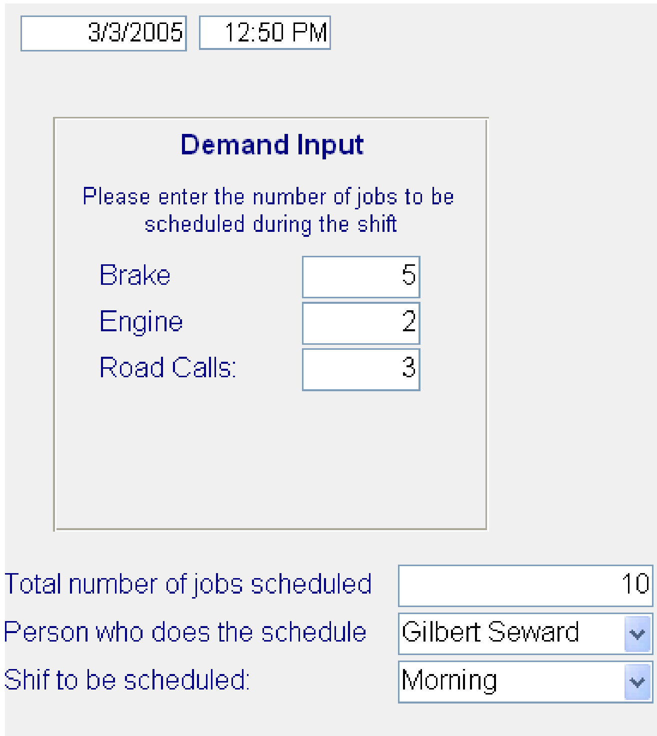

Figure 26: Database Input Form – Daily Scheduling

The list of technicians available for a normal shift scheduling is shown in figure 27.

Morning sheduling

March 2005

3/3/2005

Name	System 1	Tech. type	System 2	Tech. type	System 3	Tech. type
Mary Fisher	Brakes	A	AC	B	Road Call	M
John Smith	Brakes	A	Road Call	C	pm12k	B
Peter Louis	Brakes	M	Engine	A	Engine	B
Adam Sandler	Brakes	M	pm12k	A	AC	A
John Gilberth	pm12k	A	Road Call	B	AC	A
Darren Fink	pm12k	A	Road Call	M	AC	B
Jim Miller	Road Call	A	Brakes	B	Road Call	A
Hardy Green	Road Call	A	Brakes	B	Engine	A

Figure 27: List of Technicians Available for a Morning Shift Scheduling

CHAPTER 8

CONCLUSIONS AND FUTURE RESEARCH

8.1 Conclusions

In this study a scheduling model that combines repair time standards with forecasting methods has been developed. The contribution of this study is the combination of approaches that gives managerial applicability to the administration of transit maintenance departments. Better planning of repairs will result in cost savings, timely maintenance and reduction of road calls which translates into better and more cost effective transit service.

The model is useful to facilitate the process of resource planning on a monthly basis and the resource allocation on a daily basis. It assumes that the facility has different shops to perform repairs and PMs; each shop would have at least 10 bays and at least the same number of technicians to work in every shift.

The repair time standards developed are the result of a methodological study performed at three transit facilities and shows the process and time standardization for brakes and PMs. The forecasting model uses the moving average mathematical approach assigning a higher importance to the last two maintenance period demands for each system. The scheduling is formulated as a mathematical method and it can be applied to any maintenance system.

The results from the repair time standardization, as shown in section 4.1, reveal a significant reduction for the required time for complete brake repairs and PMs. Both systems present modular approaches that in practice represent a 27.20% and a 37.14% time reduction, respectively. The time for the first system is decreased by 67 minutes and for the second system is decreased by 148 minutes.

The forecasting method uses the maintenance historical data to model estimations of demand. Road calls are modeled and possible occurrences for the next two years are predicted. This information is useful to the managers as they can use it to schedule preventive maintenance before the breakdowns occur. The model has been tested and validated statistically.

The scheduling model is also capable of assigning the jobs to the most qualified technicians. It has been demonstrated that productivity can increase from 33% to 58% on average when technicians are assigned to perform brake jobs in a single shift. Moreover, when the jobs are assigned to the technicians with the highest performance level, additional time is gained to improve the maintenance processes.

The integrated maintenance information system is a user friendly application developed to assist maintenance managers and supervisors in the planning process of resource allocation. It presents various forms which are used to input or modify information regarding employees, fleet, daily scheduling or work orders. A series of relevant and useful reports have been designed and proven to be useful to managers. These reports are easy to read and are designed to fulfill the maintenance users' needs.

8.2 Future Research

Ongoing extensions of the current research toward the optimization of operations in maintenance departments of transit companies include:

- The standardization of all systems repaired in the facilities and for new fleet technologies. Accurate standards represent an important issue to improve maintenance processes. Furthermore, incorporating time standards of other repair jobs will enrich the scheduling model.
- The scheduling developed assumes that when a job is assigned to a bay, needed parts for the repair are always available in the warehouse. Inventory policy for spare parts is a constraint that can be added to the scheduling model to administrate the allocation of resources. Engines and transmissions are examples of very expensive parts that companies prefer to order when needed rather than having them in inventory. The availability of parts can limit the effectiveness of the scheduling model.
- A study to evaluate if the technicians should be scheduled based on the types of jobs required is recommended. That is, after developing the repair time standards for all the systems it might be better to do only brake jobs during a given shift. If that is the case, only the technicians that have high performance level on that skill should called in to work. This consideration could enhance the optimization of the resources.
- Improvements on the IMIS are encouraged to make the system more complete and manageable for users. The system could be moved to a version that allows easy migration of data to common information systems used by the transit organizations.

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APPENDICES

Appendix 1: Algorithm – Heuristic Approach

```
%Main menu that asks user to decide the type of jobs to be scheduled

option = input('Enter type of scheduling (General=1 or PMs=2): ');
if option == 1
 schmenu1
else
 schmenu2
end

%Menu that asks user to decide forescasting or current needs – General scheduling

decision = input('Forecast the demand = 1; Current demand = 2. ');
if decision == 1
 sch11        %script to run schedule from forecasted demand
else
 sch21                    %script to run schedule from current demand
end

%Menu that asks user to decide forescasting or current needs – PM scheduling

decision = input('Forecast demand? Enter 1. Current demand? Enter 2. ');
if decision == 1
 sch12        %script to run schedule from forecasted demand
else
 sch22                    %script to run schedule from current demand
end

%Start Scheduling Procedure - Repair jobs using forecasting

rc2= input ('Enter next to last demand for road calls: ');
rc1= input ('Enter the last demand for road calls: ');
eng2= input ('Enter next to last demand demand for engine replacement: ');
eng1= input ('Enter the last demand for engine replacement: ');
brk2= input ('Enter next to last demand for brakes: ');
brk1= input ('Enter the last demand for brakes: ');

rcf = (rc2+rc1)/2;       %Forecast demand of road calls with moving average(2 month
average)
engf = (eng2+eng1)/2;           %Forecast demand of engine with moving average(2 month
average)
brkf = (brk2+brk1)/2; %Forecast demand of brakes with moving average(2 month
average)
rc = round (rcf);
```

Appendix 1: (Continued)

```
eng = round (engf);
brk = round (brkf);

i = 1;              % bays counter
k = 1;              % jobs counter
b = 10;             % total number of bays

st = [480, 480, 182];   % matrix with time standards (brakes, rc, eng)
bay = zeros (3,b);      % 3 rows, 10 columns
demand  = [rc,eng,brk];          %demand to be entered to the system

p = [0.9, 1.1, 1.0, 1.0, 0.9, 1.1, 0.9, 1.0, 0.9, 1.0;
     1.0, 1.1, 0.9, 1.1, 1.0, 0.9, 1.0, 1.1, 1.0, 0.9;
     1.1, 0.9, 1.0, 0.9, 1.1, 1.0, 1.1, 0.9, 1.1, 1.1]; %technicians' performance matrix

 t = [480, 480, 480, 480, 480, 480, 480, 480, 480, 480]; %total time per bay per shift

% Do While l <= d
% Do While j <= s

if demand(3) > 16 & demand(1) > 1
 [skill,I] = max(p(1,:));
 if t(I) == 480
  bay(1,I) = bay(1,I)+1;
  p(1,I) = 0;
  p(2,I) = 0;
  p(3,I) = 0;
  t(I) = t(I) - st(1);
  demand (1) = demand (1) - 1;
  i = i + 1;
 end
end

if demand(3) > 16 &  demand(2) > 1
 [skill,I] = max(p(2,:));
 if t(I) == 480
  p(1,I) = 0;
  p(2,I) = 0;
  p(3,I) = 0;
  bay(2,I) = bay(2,I)+1;
  demand (2)= demand (2) - 1;
  t(I) = t(I) - st(1);
  i = i + 1;
 end
```

Appendix 1: (Continued)

```
end

while demand (3) > 0 & i <= b
 [skill,I] = max(p(3,:));
 bay(3,I) = bay(3,I)+1;
 demand (3) = demand(3) - 1;
 if bay(3,I) == 2 | demand(3) == 0
  p(1,I) = 0;
  p(2,I) = 0;
  p(3,I) = 0;
 i = i + 1;
 end
 t(I) = t(I) - st(3);
end

while i <= b
 if demand(3) == 0 & demand(1) >= 1
  [skill,I] = max(p(1,:));
  if t(I) == 480
   bay(1,I) = bay(1,I)+1;          % assign one job to the bay Xikj = Xikj + 1
   p(1,I) = 0;
   p(2,I) = 0;
   p(3,I) = 0;
   t(I) = t(I) - st(1);
   demand (1) = demand (1) - 1;
  end
 i = i + 1;
 end

 if demand(3) == 0 & demand(2) >= 1
  [skill,I] = max(p(2,:));
  if t(I) == 480
   bay(2,I) = bay(2,I)+1;          % assign one job to the bay Xikj = Xikj + 1
   p(1,I) = 0;
   p(2,I) = 0;
   p(3,I) = 0;
   t(I) = t(I) - st(1);
   demand (2) = demand (2) - 1;
  end
  i = i + 1;
 end

end
bay
```

Appendix 1: (Continued)

```
%Start Scheduling Procedure - Repair jobs with current demand

rc= input ('Enter demand for road calls: ')
eng= input ('Enter demand for engine replacement: ')
brk= input ('Enter demand for brakes: ')

i = 1;          % bays counter
k = 1;          % jobs counter
b = 10;         % total number of bays

st = [480, 480, 182];   % matrix with time standards (brakes, rc, eng)
bay = zeros (3,b);      % 3 rows, 10 columns
demand  = [rc,eng,brk];         %demand to be entered to the system

p = [0.9, 1.1, 1.0, 1.0, 0.9, 1.1, 0.9, 1.0, 0.9, 1.0;
     1.0, 1.1, 0.9, 1.1, 1.0, 0.9, 1.0, 1.1, 1.0, 0.9;
     1.1, 0.9, 1.0, 0.9, 1.1, 1.0, 1.1, 0.9, 1.1, 1.1]; %technicians' performance matrix

 t = [480, 480, 480, 480, 480, 480, 480, 480, 480, 480]; %total time per bay per shift

% Do While l <= d
% Do While j <= s

if demand(3) > 16 & demand(1) > 1
 [skill,I] = max(p(1,:));
 if t(I) == 480
  bay(1,I) = bay(1,I)+1;
  p(1,I) = 0;
  p(2,I) = 0;
  p(3,I) = 0;
  t(I) = t(I) - st(1);
  demand (1) = demand (1) - 1;
  i = i + 1;
 end
end

if demand(3) > 16 &  demand(2) > 1
 [skill,I] = max(p(2,:));
 if t(I) == 480
  p(1,I) = 0;
 p(2,I) = 0;
  p(3,I) = 0;
  bay(2,I) = bay(2,I)+1;
```

Appendix 1: (Continued)

```
  demand (2)= demand (2) - 1;
  t(I) = t(I) - st(1);
  i = i + 1;
 end
end

while demand (3) > 0 & i <= b
 [skill,I] = max(p(3,:));
 bay(3,I) = bay(3,I)+1;
 demand (3) = demand(3) - 1;
 if bay(3,I) == 2 | demand(3) == 0
  p(1,I) = 0;
  p(2,I) = 0;
  p(3,I) = 0;
 i = i + 1;
 end
 t(I) = t(I) - st(3);
end

while i <= b
 if demand(3) == 0 & demand(1) >= 1
  [skill,I] = max(p(1,:));
  if t(I) == 480;
   bay(1,I) = bay(1,I)+1;          % assign one job to the bay Xikj = Xikj + 1
   p(1,I) = 0;
   p(2,I) = 0;
   p(3,I) = 0;
   t(I) = t(I) - st(1);
   demand (1) = demand (1) - 1;
  end
 i = i + 1;
 end

 if demand(3) == 0 & demand(2) >= 1
  [skill,I] = max(p(2,:));
  if t(I) == 480;
   bay(2,I) = bay(2,I)+1;          % assign one job to the bay Xikj = Xikj + 1
   p(1,I) = 0;
   p(2,I) = 0;
   p(3,I) = 0;
   t(I) = t(I) - st(1);
   demand (2) = demand (2) - 1;
  end
  i = i + 1;
```

Appendix 1: (Continued)

```
end
end
bay


%Start Scheduling Procedure - PM shceduling with forecasting

bpm2= input ('Enter next to last demand for PM (12k): ');
bpm1= input ('Enter the last demand for PM (12k): ');
apm2= input ('Enter next to last demand for PM (6k): ');
apm1= input ('Enter the last demand for PM (6k): ');

apmf = (apm2+apm1)/2;        %Forecast demand of PM (6k) with moving average(2
month average)
bpmf = (bpm2+bpm1)/2;        %Forecast demand of PM (12k) with moving average(2
month average)

apm = round (apmf);
bpm = round (bpmf);

i = 1;          % bays counter
k = 1;          % jobs counter
b = 10;         % total number of bays

st = [252, 200];          % matrix with time standards (brakes, rc, eng)
bay = zeros (2,b);      % 2 rows, 10 columns
demand  = [bpm,apm];          % demand to be entered to the system

p = [0.9, 1.1, 1.0, 1.0, 0.9, 1.1, 0.9, 1.0, 0.9, 1.0]; %technicians' performance matrix

t = [480, 480, 480, 480, 480, 480, 480, 480, 480, 480]; %total time per bay per shift

while i <= b
 if demand(1) >= 1
  [skill,I] = max(p(1,:));
   bay(1,I) = bay(1,I)+1;          % assign one job to the bay Xikj = Xikj + 1
   t(I) = t(I) - st(1);

 demand (1) = demand (1) - 1;
   if demand(2) >= 1
    bay(2,I) = bay(2,I)+1;         % assign one job to the bay Xikj = Xikj + 1
    t(I) = t(I) - st(1);
    demand (2) = demand (2) - 1;
   end
```

Appendix 1: (Continued)

```
   p(1,I) = 0;
  end
 i = i + 1;
end

bay
p;
demand(1);
demand(2);

%Start Scheduling Procedure - PM scheduling with current demand

bpm= input ('Enter demand for PM (12k): ');
apm= input ('Enter demand for PM (6k): ');

i = 1;              % bays counter
k = 1;              % jobs counter
b = 10;             % total number of bays

st = [252, 200];          % matrix with time standards (brakes, rc, eng)
bay = zeros (2,b);      % 2 rows, 10 columns
demand  = [bpm,apm];           % demand to be entered to the system

p = [0.9, 1.1, 1.0, 1.0, 0.9, 1.1, 0.9, 1.0, 0.9, 1.0]; %technicians' performance matrix

 t = [480, 480, 480, 480, 480, 480, 480, 480, 480, 480]; %total time per bay per shift

while i <= b
 if demand(1) >= 1
  [skill,I] = max(p(1,:))
   bay(1,I) = bay(1,I)+1           % assign one job to the bay Xikj = Xikj + 1
   t(I) = t(I) - st(1);
   demand (1) = demand (1) - 1;
   if demand(2) >= 1
    bay(2,I) = bay(2,I)+1          % assign one job to the bay Xikj = Xikj + 1
    t(I) = t(I) - st(1);
    demand (2) = demand (2) - 1
   end

 p(1,I) = 0;
 end
 if demand(1) == 0 & demand(2) >= 1
   bay(2,I) = bay(2,I)+1           % assign one job to the bay Xikj = Xikj + 1
   t(I) = t(I) - st(1);
```

Appendix 1: (Continued)

```
   demand (2) = demand (2) - 1;
   i = i + 1
 end
end
bay
p
demand(1)
demand(2)
```